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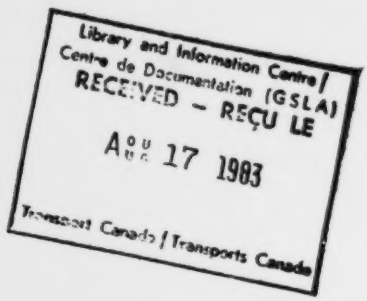
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FINAL REPORT
ON
FRASER FORESHORE SEDIMENT TRACING PROJECT

PREPARED FOR
TRANSPORT CANADA
CANADIAN COAST GUARD
WATERWAYS DEVELOPMENT DIVISION
OTTAWA, ONTARIO

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1. PURPOSE

The study objective was to determine the net direction and transport rate of bedload sediment over the Fraser River foreshore area. Data were to be collected during the period of peak river discharge and sediment transport and correlated to river discharge, tide, and wind conditions. Specific conclusions or results expected from the study were:

i. the determination of the net bedload transport directions and fluxes by grain size fraction over the Fraser foreshore,

ii. an improved understanding of the relationship between sediment movement, river discharge and tidal currents on the Fraser foreshore,

iii. estimation of the dispersion coefficients of bedload sediment on the foreshore,

iv. further development of techniques for measuring sediment movement which will be usable in future engineering and environmental studies on the Fraser estuary and in other regions of Canada.

The study was conducted for the Waterways Development Division of the Canadian Coast Guard under the terms of the Department of Supply and Services Canada, file number 17SU.T8080-2-0165.

2. SUMMARY

A sand tracing study was undertaken to determine the net direction and transport rate of the sediment moving as bedload in the Fraser River foreshore area and to determine its response to river discharge, tides, and wind waves. Native sand was collected from nine stations on the foreshore, tagged with fluorescent rhodamine WT dye and replaced in its original locations. Subsequent excursions were made at intervals to collect sand samples from a specified grid surrounding the nine stations. These samples were analyzed in the laboratory to determine the percentage of tracer sand present and hence the pattern of sand movement. These field measurements were augmented by measurements of water currents, wind velocities, and discharge rates from the Fraser River.

Averaged values of bedload dispersion were determined for each of the nine stations based on the results of the tracer sand measurements. These were compared to bedload transport rates as measured on several occasions by a bedload sampling device and as calculated from a theoretical "Ackers-White" formulation. A numerical model was developed for the foreshore based on an extended version of de Vries' sediment dispersion model.

The results showed that advection rates determined over Sturgeon and Roberts Bank were generally less than 0.3 m/day, Figures 1 and 19. A maximum advection rate of 0.35 m/day was determined at Station 9.

Sand movement over the outer stations on Sturgeon Bank was more influenced by wave action at low tides than by tidal action. Sand movements at stations on Roberts Bank were primarily influenced by ebb tide and river discharge flows. Sand movement at Station 4 was not directly affected by flow through the Steveston Jetty gap at Garry Point.

3. CONCLUSION

1. The average advection rates for most stations across Roberts and Sturgeon Banks were small, with values of 0.3 m/day or less, Figure 19. The largest advection rate was found for Station 9 near Canoe Pass, Figure 1, with an average southerly rate of 0.35 m/day.

2. Sand movement on Sturgeon Bank was generally small. Offshore locations were more affected by wave action during the study period than by tidal currents. Station 4, near Garry Point, was more affected by tidal action than by waves, Table V, and showed no effects of flow through the gap in Steveston Jetty.

3. Sand movement on Roberts Bank was appreciably greater than on Sturgeon Bank and was primarily induced by tidal action and the Fraser River discharge.

4. Local dendritic drainage channels affect the direction of bedload transport across Roberts Bank by altering the general direction of the ebb flow currents.

5. Bedload transport rates were determined for Station 6 by three different methods. The results were:

   i. 0.03 m^3/day per unit width calculated from isoconcentration contours;

   ii. 1.4 m^3/day per unit width calculated from bedload sampler measurements;

   iii. 0.4 m^3/day per unit width calculated using theoretical Ackers-White formulation.

   A rate of between 0.1 to 0.4 m^3/day per metre width is a reasonable estimate of bedload movement at Station 6 during the study period.

6. Sand grain sizes and gradation over the foreshore area were too uniform to allow the total transport rates to be broken down into grain size fractions.

7. Average diffusion values ranged from 4.5 m^2/day at Station 6, followed by 3.3 m^2/day at Station 8, down to 0.2 m^2/day at Station 3. The diffusion was the greatest along the axes of predominant tidal currents.

8. The tidal current measurements at Station CM1 showed very little influence from either the Fraser River discharge or wind.

9. The tidal currents measured at Station CM2 were strongly influenced by the Fraser River discharge. If the tidal flow was a weakly flooding flow, the current direction at CM2 would not change to a flood direction, but rather the current would weaken in strength and maintain its ebb-direction orientation. It was found that the tidal current flow could be influenced by the wind to a certain extent.

10. An extended version of de Vries' sediment dispersion model was developed in an attempt to model the sand movement on the foreshore, Appendix D. The time evaluation of the peak tracer concentration at the placement point was acceptably reproduced by the numerical model when values of diffusion and advection from the field data were used as inputs to the program. However, calculated values for the spread of tracer sand over the study area were higher than observed value due to a significant loss of dye in the field due to abrasion and leaching during the study period.

11. Rhodamine WT dye was found to be more appropriate than rhodamine B for use as a sand tracer due to its ease of handling, higher achievable concentration on the sand particles, and durability.

12. A dye concentration of 5% rhodamine WT was found to be the optimum concentration to bond to the Fraser foreshore sand.

13. A series of laboratory tests conducted on the dyed sand indicated that a small percentage of the dye may leach out from the washing action of seawater in the field and that a large amount of dye may be lost due to abrasion of the sand particles against one another while they are moving.

14. The dye mixture coated the sand particles to a thickness of between 0.025 mm and 0.05./mm. The size of the individual grains was found to have no effect on the fluorometer calibration.

4. INTRODUCTION

4.1 Description of Fraser Foreshore

The Fraser River, draining 230,000 square kilometers of watershed, supports the largest salmon runs of any river in North America and provides major shipping facilities as far upstream as New Westminster. The river is vitally important to the economy of British Columbia.

As the river passes through New Westminster, it splits into two main distributary arms to flow past Lulu Island. These distributaries split again to flow past Sea Island to the north and Westham Island to the south on the inner edge of the delta-front, Figure 1. Of the four channels that finally drain the Fraser River into the Strait of Georgia, the South or Main Arm accounts for 75% of the river outflow. The North Arm accommodates 15% of the flow and the Middle Arm and Canoe Pass 5% each.

Deposition of sediments from the Fraser River has created a delta whose age has been estimated at approximately 8000 years. At the time of its initial formation, the last ice age had just ended and the Fraser River had begun to develop a deltaic plain from the present location of New Westminster. Since that time sediment has been added to the delta at an average rate of 12 million cubic metres per year. The deltaic sediments presently overlay glacial deposits to an average depth of 120 metres and a maximum depth in excess of 200 metres (Thompson, 1981). The delta-front stretches for 37 kilometres from Point Grey in the north to Point Roberts Peninsula at the south end. Luternauer and Murray (1973) sub-divided the delta-front into three sedimentary environments: salt marsh, main platform, and upper foreslope with the following characteristics:

i. The salt marsh is a flat to hummocky region near the high tide level. It supports vegetation and occupies a zone about one kilometre wide. The sediments on the salt marsh are generally less than 0.063 mm in diameter.

ii. The main platform consists of the tidal flats below the salt marsh. This area is very flat with an average slope of 1½° for about 6 kilometres out

from the salt marsh to the break in slope at about 9 metres below lowest normal tide level. The sediments range from 0.35 mm to 0.125 mm.

iii. The upper foreslope is defined by Luternauer and Murray as the region from the main platform to the 90 metre depth. This region has a variable slope with a maximum inclination of 12°. The sediments are muddy at and north of the main river channel but are mostly sandy south of the main channel.

4.2 Factors Influencing Foreshore Characteristics

The Fraser River discharge varies considerably from year to year. Within any one year the snow-melt, which constitutes two-thirds of the total runoff, begins in April and increases to a maximum freshet in late May and early June. The discharge decreases markedly by late August and reaches a minimum by early December. This low level is maintained until the spring. The average daily discharge at Hope between the years 1912 and 1956 was 570 cubic metres per second in winter and 8800 cubic metres per second in summer. Most of the sediment supply is transported to the delta front during the freshet each year. The river channels become naturally unstable as they cross the delta. Stabilization of the Main Arm and the North Arm have been achieved only as a result of training wall construction and periodic dredging. Comparison of aerial survey photographs taken in 1967 and 1978 show that the channel from Canoe Pass to the foreslope has changed its course markedly over that period.

The tides in the Strait of Georgia are of the mixed semi-diurnal type, having two high tides and two low tides every day with inequalities both in height and time. The range of tidal heights between high and low varies in an approximate two-week cycle with large ranges being designated spring tides and small ranges neap tides. In the southern part of the strait, the tidal currents flood in a general northerly direction and ebb in a southerly direction. The flood currents tend to be greater in magnitude and of longer duration than the ebb currents, resulting in a net northerly drift. The tidal currents that flow over the Fraser foreshore are influenced by the river discharge and local bathymetry which can affect their speed and direction significantly.

Winds created from large coastal pressure systems in south-western British Columbia are modified by the Fraser Valley and local north-shore mountains. The

prevailing wind direction over the Fraser foreshore is from the west. The strongest winds tend to blow from the northwest, and occasionally, from the southwest. In the summer, the local winds are dominated by a sea-land breeze circulation, with westerly sea breezes during the day and easterly land breezes out onto the strait during the night. In the winter there are occasional strong outflows of cold arctic air that pour down the mountain valleys and create strong easterly winds across the Fraser foreshore.

One of the main features of the foreshore that affects large scale sedimentation characteristics has been the introduction of man-made structures. Since 1911, the Steveston Jetty, Albion Dykes, North Arm Jetty and Iona Jetty have been constructed. The most recent structures have been the Roberts Bank Causeway and Superport which were built south of Canoe Pass in 1971 and are currently being enlarged. One of the effects of these structures is to impede the access of tidal currents to the inner foreshore and to alter the flows across the intertidal flats.

4.3 Foreshore Dynamics

Most regions of the Fraser foreshore are in a state of constant flux. The delta front off Sturgeon Bank advances in a seaward direction at a rate of about 2.3 metres per year at the low water mark and 4.6 metres per year at 30 metres depth. The front near the main channel mouth has been advancing an average of 8.5 metres per year at moderate depth but appreciably less in shallow water (Mathew and Shepard, 1962). Contrary to the situation on Sturgeon Bank, the southern part of the Roberts Bank delta-front at a depth of 30 metres appears to be retreating inland at a rate of 12 metres per year (Thompson, 1981).

Historically, there has been major channel instability throughout the Main Arm, although this has been largely stabilized with the construction of the Steveston Jetty and other training works. Canoe Pass channel is subject to migration and avulsion on the outer two-thirds of Roberts Bank, but appears to be relatively stable across the inner one-third.

Tamburi and Hay (1978) indicated that there was no strong evidence of longshore transport along the inner edge of the foreshore mainly due to two reasons. The first reason was that incoming waves tend to be refracted such that their crests are parallel to

the high water mark during high tide. Secondly, the great friction losses imposed on a wave system by bottom drag across the shallow banks leaves little energy for breaking waves along the inner edge. Tamburi and Hay concluded that tidal currents provide the primary dispersion mechanism for sediments on the foreshore, and that this mechanism is most effective in deep water toward the delta edge. Bottom drag makes tidal currents a relatively ineffective transport mechanism along the inner edge of the delta.

The interaction of river flow with tidal currents results in periodic fluctuations of sediment movement near the main channel. During the ebb tide, bedload transport which is in the direction of river flow in the main channel swings toward the south as it exits from the mouth of the Fraser at the inner edge of the banks. As the tide floods, tidal currents carry bed material north from the channels.

During the flood tide a bottom layer of dense, saline water moves upstream into the larger channels underneath the outflowing fresh river water. This layer of saline water is called a salt wedge and can move as far as 22 km upstream of Steveston on the rising tide, depending on river discharge and tidal height conditions. This wedge effectively stops bedload transport to the channel mouth. Tamburi aand Hay (1978) indicated that although bedload transport can be stopped by the salt wedge, suspended sediments and wash load can still be transported to the mouth in the upper layer of fresh water and from there northward over the inundated Sturgeon Bank.

4.4 Previous Studies

Several agencies and individual investigators have studied the Fraser River foreshore sediment morphology and related physical processes. The University of British Columbia, Public Works Canada, Environment Canada, and the Geological Survey of Canada have all conducted studies in various regions of the Fraser Delta. The most recent description of this area is included in the International Association of Sedimentologists' Field Excursion Guidebook for Excursion 30A: Late Quaternary Sedimentary Environment, Southwestern British Columbia, 1982. This report was written by J.J. Clague and J.L. Luternauer and includes an extensive list of references to past investigations.

The previous studies have been based mainly on isolated sampling programs of material from the foreshore, on photographic comparisons and on the theoretical application of hydraulic and sedimentological knowledge. The present study was developed to provide on site measurements of actual sediment movements over a period of Fraser River freshet conditions. The study was to examine directions and rates of both net transport movement and dispersion of sand sediments at selected locations on the foreshore near the mouths of the Fraser River.

5. FIELD WORK

5.1 Planning

5.1.1 Selection of Sites

The dye tracing technique proposed for the sediment movement study has been found suitable for tracking sand sized particles. Particular sand areas on the Fraser foreshore were identified from aerial photographs. Following discussions with the Canadian Coast Guard and other government agencies, nine study locations were selected to give a broad coverage of Roberts Bank and Sturgeon Bank, Figure 1. The selected sites were:

Site 1	on the outer bank of the entrapped area between the solid Iona and North Arm Jetties.
Site 2	in an area of anticipated little movement between Iona Jetty and Middle Arm near to the existing Iona sewage outfall ditch.
Site 3	near the centre of Sturgeon Bank opposite Richmond.
Site 4	at the nearshore end of the north side of the Steveston Jetty, an area of environmental concern close to a proposed dredge spoil site.
Site 5	near the seaward end of the Steveston Jetty, on the north side, an area exhibiting large sand dunes in a regular pattern.
Site 6	on the south side of the entrance of the Middle Arm to the foreshore area.
Site 7	on the south side of the Middle Arm near the seaward end of the Steveston Jetty.
Site 8	near the centre of Roberts Bank opposite Westham Island.
Site 9	on the south side of the Canoe Pass channel.

The actual establishment of the nine stations in the field was accomplished as closely as possible to the planned locations depending upon local restrictions such as unexpected channels, low-lying areas, beds of eel grass, and areas of fine clayey silt.

5.1.2 Study Schedule

The study stations, having different surface elevations, were exposed for varying lengths of time at low tides. A program was drawn up, Figure 2, to allow surface sampling to be made in the dry at each station. The program allowed two weeks for dyeing of the native sand after its initial capture from each station.

Station 1 was chosen in an area of its expected quiesence and lack of response to the Fraser freshet to be a test site for the purpose of establishing the best operating procedure for the main part of the field program. Sampling and dye studies commenced at this station prior to the arrival of the freshet. The timing of the sand deposition and sampling program at the other stations were scheduled in an attempt to coincide with the peak of the spring freshet of the Fraser River, Figure 3. The first priority of timing went to the Roberts Bank stations which were felt to be impacted more greatly by the river than the Sturgeon Bank stations.

The Roberts Bank stations (Stations 6 to 9) were studied between June 18 and July 9, during which time the Fraser freshet reached its maximum flow conditions and started to wane. The Sturgeon Bank stations were studied before (Stations 1,2,3) and after (Stations 4 and 5) the main peak of the freshet.

5.2 General Procedure

Approximately 200 kilograms of native sand were obtained from a 10 m^2 surface area at each selected station. This sand was returned to the lab, analyzed for size distribution, Figure 4, and coated with Rhodamine WT fluorescent dye as described in Section 6. The dyed sand was then returned to the original sites and deposited, Figure 5A. In order to be as efficient as possible, these stations were visited in pairs, one at a relatively high elevation and the other at a relatively low elevation. The sites were revisited at daily and weekly intervals to obtain recaptured samples of the sand over a specified grid pattern.

The recaptured samples were reanalyzed at WCHL to determine the proportions of dyed and undyed sand. The amount of dyed sand found at each grid sample point was used

to determine the rates of net transport and lateral dispersion of sand at the study stations.

Supplementary field data were obtained to augment the dyed sand measurements. Two self-contained, continuously recording, acoustic current meters were deployed at Stations CM1 and CM2 on Sturgeon and Roberts Bank respectively, Figure 1. Continuous current readings were obtained at 0.2 m above the seabed at both locations during the two month interval of May 26 to July 23, 1982. The two self-recording current meters were deployed at Stations CM1 and CM2 on May 26, serviced (change of magnetic tape, batteries, etc) on June 23, and retrieved on July 23, Figure 4B. They functioned correctly throughout their period of deployment. In addition, a 12-hour time series of current profiles and bed-load sampling was carried out at each study site within the period of time that the sand movement was being studied at that station. Four series were undertaken in total, each series covering the locations of two stations. Measurements of aggradation and degradation were made at each sampling station with implanted depth-of-disturbance rods and free riding washers. Estimates of sediment transport rates were made at several stations using a semi-buried sediment pan. More complete details of the study techniques are given below.

5.3 Establishment of Stations and Placement of Dyed Sand

The station locations were identified by a steel centre post driven into the sand. Each post had a bright red witness buoy attached so that it could be located when the station was under water, Figure 6A. The dyed tracer sand was spread in a solid circle centred at the centre post. The diameter of the circle was approximately three metres and the thickness two centimetres to correspond with the height of local sand ripples. The dyed sand at Station 1 was recessed into the ground such that the upper surface of the dyed sand circle was flush with the ambient sand surface, Figure 5A. It was found that the dyed sand tended to be subsequently buried by moving surface sand using this method, Figure 6B. The dyed sand at the other stations was placed on top of the foreshore surface.

At each station, five control samples of dyed sand were placed in small porous bags and secured at the seabed well clear of the sampling area. These control samples were

used to assess any loss of dye from the sand particles due to leaching in the salt water. One bag was collected each time the station was visited for sampling.

At Stations 5, 6, 7, and 9 a partitioned sediment pan trap was recessed into the surface so that its lip was flush with the sand floor. The pans were located on the edge of the sampling grid area at about 15 m from the centrepost. The pans were left in place for 1 or 2 days prior to analysis of how much sand had collected in each partitioned area. This was used to obtain a rough estimate of the bed load flux in four directions.

Whenever stations were visited, visual observations of bedforms and weather (wind, waves, etc.) were made. Photographs were taken to document prominent features of the particular station or dyed sand movement. Visual observations of dyed sand patterns and distances of migration were recorded.

5.4 Measurements of Dyed Sand Movements

During placement of the dyed sand, four marker rods had been driven into the sand at a distance of 15 metres from each centre post, one in each of the magnetic directions of north, east, south, and west. Wide metal washers had been placed over these rods to rest on the sand, Figure 7A.

Measurements were taken during each visit of the distance between the top of each depth of disturbance rod to the sand surface and of the distance from the top of the rod to the washer. Comparison of these readings showed the amount of aggradation and/or range of vertical movement at each site.

A sampling corer for recapturing sand from each grid point was made up out of a thin walled, clear plastic graduated cylinder with a bevelled cutting edge, Figure 7B. The coring tube was fitted with a plunger which was pulled up as the tube was pushed down to facilitate the drawing of the sand sample into the tube. The tube was 30 centimetres in length and had an inside diameter of 6.35 cm. Core samples of exactly 10 centimetres in length from the surface were collected and placed in plastic locking freezer bags for later analysis. The coring depth of 10 centimetres was judged by initial visual inspection to be deeper than any dyed sand migration.

The basic sampling grid for each station consisted of a square, 30 metres by 30 metres, centred on the centre post. The main axes of the grid were oriented in magnetic north-south and east-west directions. A sample spacing of 5 m intervals was used so that 49 samples would be taken from the basic grid, Figure 7C. As the sampling program progressed from one station visit to the next, the grid was offset depending on the extent and direction of dyed sand movement to ensure that the boundaries of the tracer sand "cloud" were delineated, Figure 7D.

At each station, depth profiles were taken along the axis of apparent dyed-sand movement. These core samples were obtained using lengths of 7.62 centimetre inside diameter P.V.C. tubing which were pushed as deeply into the sand as possible. The sand was kept in the tubes and frozen at WCHL. The frozen sand cores were ejected from the tubes and sliced into three-centimetre layers and the inside parts of the layers were analyzed for tracer sand. This technique allowed analysis of the movement of tracer sand to varying depths below the surface while avoiding contamination of the samples from layer to layer along the inside wall of the coring tube.

The data gathering during each visit to each site also included acquisition of a dyed-sand control sample, observation of bedforms (size and orientation), collection of sand from partitioned sediment pan (if present), and weather observations.

5.5 Current Profiles and Bedload Samples

Each station was visited for a period of twelve hours during the sand tracking period over which current speed and direction were measured at two depths (0.2 and 0.8 of the total depth) using a boat-suspended Price current meter. These measurements were made to give a pattern of ebb and flood velocities at each site which could be compared to the continuous current meter recordings to obtain an approximate current history at each point over the tracking period. During the current metering period, a bedload sampler was lowered to the sea floor near peak ebb and flood currents and left for several minutes to measure any bedload movement.

Each twelve-hour time series was conducted with a single boat moving between two stations on each day. Stations 2 and 3 were monitored together during one twelve-

hour period, as were Stations 4 and 5, 6 and 7, and 8 and 9. There were no time series velocity measurements made at Station 1.

5.6 Moored Current Meters

Two Neil Brown acoustic current meters were moored by Seakem Oceanography Limited in the study area for the duration of the field measurements. Each mooring consisted of a steel tetrapod frame which sat on the seafloor with the current meter securely fastened within it. These sites were selected to record flow conditions typical of those occurring over Sturgeon and Roberts Bank while being near to the high flow velocity area at the mouth of the Fraser River Main Arm. The current meters measured current speed and direction, and water temperature. Averaged values of these parameters plus a "status parameter" which indicated whether the meter was in the water or exposed due to low tide were recorded on magnetic tape every 20 minutes.

5.7 Study Vessels

A Canadian Coast Guard hovercraft was used for the initial collection of native sand and the replacement of dyed sand at all stations except Station 1. The advantages of this craft were its speed, its ability to travel anywhere on the foreshore regardless of tidal height, and its substantial weight lifting capacity.

A helicopter was used by Seakem Oceanography Ltd. to install the current meter moorings at Stations CM1 and CM2. The current meters were subsequently serviced and retrieved using the Coast Guard hovercraft.

The tracer sand sampling trips were made using a nineteen foot Gregor aluminum river boat powered by twin outboard jet motors. The boat and motors were of sufficiently shallow draught to enable the investigators access to shallow water areas. This boat was also used for the twelve-hour time series of current profiling and bedload sampling.

6. PREPARATION AND ANALYSIS OF TRACER SAND

6.1 Preliminary Dye Tests

6.1.1 Choice of Dye

Prior to commencing the main part of the study, a number of laboratory tests were conducted to determine improvements to previous techniques and to assess characteristics and durability of the dye coating on the sand. The first concern was the feasibility of using a more serviceable fluorescent dye than the rhodamine B which had been used in previous work (WCHL, 1979).

Rhodamine WT dye was considered more appropriate to the present study than rhodamine B for the following reasons:

i. Possible use of higher concentrations - in laboratory tests, it was found that a higher concentration of fluorescent dye could be attached to the sand particles if rhodamine WT rather than rhodamine B were used.

ii. Ease of handling - rhodamine WT was obtained commercially in a 20% solution which was easier and less messy to handle than the rhodamine B which was available only in powdered form.

iii. Durability - rhodamine WT has been found to deteriorate more slowly under the influence of sunshine and unbalanced pH than rhodamine B (Carter, 1974).

6.1.2 Choice of Concentration

A series of tests was conducted to determine the most suitable concentration of rhodamine WT dye to bond to the sand particles. In these tests, dye of varying concentrations between 1.5% and 20% was bonded to separate batches of sand. The sand was then soaked in water for a week, washed until no further colour loss could be seen, and analyzed for fluorescence. The tracer sand with very high dye concentrations (15-20%) would not rinse clean and still had abundant dye being released after 1 weeks soaking

plus 48 hrs rinsing. Sand with lower dye concentration showed greatly reduced leaching characteristics after washing.

It was decided from the results of these tests that a dye concentration of 5% should be used as it washed clean within a reasonably short time and yet left ample dye on the sand to permit analysis for low concentrations.

6.1.3 Dye Deterioration

A laboratory test was conducted into the leaching characteristics of the bonded 5% dye. This test consisted of placing 500 grains of dyed sand on a fine screen and flushing it with running water continuously over a period of 48 hours. The fluorescence of this sample was compared to the fluorescence of unwashed dyed sand from the same batch. The dye fluorescence diminished by about 17 percent over a period of 5 days. It was anticipated that any leaching of further dye from the washed sand placed on the foreshore could be calibrated against the use of small control samples placed in porous fine mesh bags at the sample stations.

A laboratory test was conducted to determine if physical abrasion of the tracer sand particles could be a significant dye deterioration process. Several batches of tracer sand were placed in salt water and severly shaken by mechanical agitator for varying lengths of time. The samples were then washed and tested for fluorescence. The results showed that 66% of the dye was lost when the sand was shaken for 20 minutes, 70% lost after 30 minutes, and 71% lost after 60 minutes. Although these results could not be used to calibrate the deterioration effects of the dye due to sand movements on the Fraser foreshore, they did indicate that it was possible for a large amount of dye to be abraded from the surface of the sand grains and lost but that such losses would largely occur during initial movement shortly after being placed.

6.1.4 Effect of Dye Coating on Grain Size

A test was conducted on the sand obtained from Station I to determine the effect of the dye coating on the grain size. The native sand had the following size characteristics:

D_{50} = 0.45 mm
D_{90} = 0.55 mm

while the dyed tracer sand had the characteristics:

D_{50} = 0.50 mm
D_{90} = 065 mm

These results indicate that the thickness of the dye layer on the sand grains was between .025 mm and 0.05 mm. The dye coating reduced the average specific gravity of the sand grains from 2.66 to 2.33 and increased the average submerged weight of the grains by less than 10%.

6.1.5 Effect of Grain Size on Fluorometer Calibration

A test was conducted to determine the effect of grain size upon fluorometer calibration. Native sand from Station 2 on Sturgeon Bank was screened to two different size ranges: i) less than 0.300 mm; and ii) between 0.300 mm and 0.595 mm. Dyed sand from the same station was selected on the same basis. By manually counting grains of sand, samples from both size groups were made up of 500 total grains, each sample having either 1, 5, 10, or 20 grains of dyed sand, with the rest being composed of undyed sand. These samples were analyzed for fluorescence. There was virtually no difference in the results from the two different grain size ranges. It was concluded that the fluorometric calibration technique for determining concentration of dyed sand in native sand was not affected by a moderate difference in grain size.

6.2 Preparation of Tracer Sand

The 200 kg samples of tracer sand for each station were prepared following proven techniques (Teleki, 1966; Russell, 1960; and WCHL, 1979). Fluorescent rhodamine WT dye was bonded to sand particles in the following fashion:

i. Clean, dry, native sand was placed in a portable cement mixer.

ii. Urea formaldehyde and rhodamine dye were added to the sand and mixed for ten minutes. The urea formaldehyde acted as a bonding agent to bond the dye in a layer around each sand particle.

iii. Ammonium chloride was added to the mixture to act as a catalyst and this was mixed for a further ten minutes.

iv. The sand mixture was spread out on a flat surface for drying. The drying process was enhanced with the use of propane heat blowers.

v. After the mixture had dried, it was broken up into chunks and passed through a grinder to separate the sand particles.

vi. The sand was then thoroughly washed and seived to get rid of any large chunks and dust or fine particles of free dye.

The quantities of chemicals used to prepare a batch of 200 kg of tracer sand with a final 5% concentration of rhodamine dye were as follows.

1.	Clean, dry native sand	168 kg
2.	Rhodamine WT fluorescent dye solution at required concentration	42.5 kg
3.	Urea formaldehyde (bonding agent)	31.8 kg
4.	Ammonium chloride (catalytic agent)	3.18 kg

Stock rhodamine dye was obtained in a solution of 20% concentration. This was diluted to the desired final concentration taking into account the volume of water already present on the sand if wet sand was used.

6.3 Dye Retrieval Procedure

Sand which had been dyed, placed at an injection site on the foreshore and subsequently recaptured during the sampling program was analyzed in the laboratory as follows:

i. Each sample was dried in an oven for six hours to permit accurate weighing.

ii. The sample was well mixed and 100 grams of the sample were weighed out for analysis.

iii. A mixture of 4% by volume of 11.6N concentrated hydrochloric acid, 24% denatured alcohol (ethanol), and 72% tap water was added to each sample. The sample was stirred vigorously, covered to avoid evaporation, and allowed to sit for two hours. The sample was stirred periodically throughout this digestion period.

iv. In addition to the tracer samples, blanks were prepared consisting of the acid/alcohol/water solution alone and the acid/alcohol/water solution and native sand. These blanks were used to determine the background levels of the native sand and the elution chemicals.

v. After two hours of digestion, the elute containing the dissolved rhodamine dye was filtered into pyrosilicate cuvettes for use in the fluorometer. The filtering procedure effectively removed all of the suspended solids from the filtrate.

vi. If the filtrate appeared as a pink solution, then it was diluted in an appropriate fashion until its fluorescence was within the operating range of the fluorometer.

vii. A cuvette containing the filtrate was then placed in a Turner Mark 10 fluorometer and the relative fluorescence reading was taken immediately to avoid temperature effects on the fluorescence levels.

6.4 Reduction of Tracer Sand Data

6.4.1 Fluorescence Calibration

The fluorometer was calibrated separately for each site by the following technique, using samples of dyed sand obtained from that site:

i. After being coated with dye as described in Section 6.1, a sample of the tracer sand was washed thoroughly to remove any residual rhodamine dye from the surface of the tracer sand grains.

ii. Varying proportions of dyed sand were mixed with native sand to establish standards for the concentration of tracer sand, defined as:

$$\text{concentration} = \frac{\text{number of grams of tracer sand}}{\text{total number of grams of sample}}$$

iii. Samples of each different concentration standard were then analyzed as described in Section 6.2.

iv. The relative fluorescence readings from the fluorometer were used to prepare a calibration curve relating tracer sand concentration to a specified fluorometer reading. A typical fluorometer calibration curve, as determined for Station 2, is shown in Appendix A. Confirmatory observations for the calibration technique, based on actual hand-count samples, are also shown on the calibration curve.

6.4.2 Isoconcentration Contouring

The tracer sand concentration values obtained from the laboratory analysis gave the percentage of tracer sand present in a particular sand sample containing both native sand and tracer sand. Since each ten centimetre deep core sample had been thoroughly mixed before the analysis portion was taken from it, this concentration value was an average over ten centimetres of depth. The concentration values were plotted on a grid similar to the station sampling grid and contour lines of equal concentration were drawn for each site and each sampling visit. Plots of the "isoconcentration contours" for Stations 2 to 9 are summarized on Figures 8 to 15 and are shown in detail in Appendix B. Comparison of contours between succeeding visits showed the spreading and general direction of movement of the tracer sand at each station. Studies at Station 1, undertaken primarily to establish sampling technique, were not as complete as at the other sites.

7. SITE OBSERVATIONS

7.1 Wind, Current and Auxiliary Observations

7.1.1 Data Reviewed

Movement of bed material on the Fraser foreshore is a result of water motion produced by the following phenomena: wind stress at the water surface, waves, tides, and flow from the Fraser River. In order to analyze and interpret the movement of bed material at each station as indicated by the isoconcentration diagrams, the following data obtained during the study period were used:

(a) Wind speeds and directions measured at Vancouver Airport.

(b) Predicted tidal levels at Point Atkinson.

(c) Current metering at the two fixed positions CM1 and CM2.

(d) Current metering on one day at each of the stations.

(e) Observations of winds, sea waves, sand ripples and sand dunes made during site visits to each station.

(f) Accretion or erosion at each station as indicated by depth of disturbance rods.

(g) Fraser River discharge.

All field data directions were related to bearings from true north and are so referred to in this report.

Site conditions and bedform observations taken during the study period at Stations 2 to 9 are summarized on Figures 8 to 15.

7.1.2 Wind and Waves

Wind speeds recorded at Vancouver Airport during the period May 1 to July 31, 1982 were obtained from the Atmospheric Environment Service. During the course of the study winds were generally light. The predominant wind directions were both easterly and westerly with maximum wind speeds occurring from the W and WNW. During the latter part of the study, easterly winds predominated over westerly. Wind speed and direction percentage exceedence curves are shown in Figure 16.

Wind speeds and directions were used to hindcast waves at Sand Heads using methods of the U.S. Army Corps of Engineers (1981). Winds from direction between SSE through W to N blew over deep water fetches. Winds from other directions could only generate waves towards the study stations in shallow water. Deep water waves were hindcast for "storm" periods when average wind speeds exceeded 20 km/hr. Shallow water waves were hindcast when average wind speeds exceeded 17 km/hr. Wind speeds, fetch lengths, and hindcast wave heights and periods are shown in Tables I and II.

The maximum wave height hindcast for the study period occurred during the storm of May 25 when significant wave heights were hindcast up to 1.43 m. Generally wave heights were much lower than this, westerly storms producing significant wave heights of about 0.5 m, easterly storms producing significant wave heights of about 0.25 m. The significant wave height represents the mean height of the highest 1/3 waves. Although over 13% of all waves will exceed this height the significant wave height has been found to typify wave conditions causing bed movement or shoreline damage in most storms.

Hindcast wave heights and wind speeds and directions measured at the airport were compared with observations made during each visit to the study area. Due to the approximate nature of inshore field wave observations made during the boat journey to and from a site, the comparison was inconclusive. Differences were frequently noted between wind speeds and directions measured at individual stations and those recorded at the airport. This was probably due to both the difference in elevation between the stations and the airport anemometer and to local topography. This finding was consistent with simultaneous observations which had been made previously at Sand Heads and 8 km offshore of Sand Heads (Tabata et al, 1971).

Refraction of waves across the Fraser foreshore occurs when water depths are sufficiently shallow to affect the relatively short periods waves. Both Sturgeon and Roberts Bank are uncovered at low water and depths over the banks are quite shallow for a significant proportion of the tidal cycle. The effects of winds and waves on bed movement are therefore dependent on the tidal stage. Calculations for Sturgeon Bank showed that the amount of refraction occurring with W and WNW deep water waves was not significant. On Roberts Bank, refraction was more pronounced but averaged less than 10° in the direction of crest travel for westerly waves and less for SW waves during times when there was more than 1 m water depth. Due to the low height of generated waves, the influence of the easterly storms on bed movement was minimal. No effects of easterly storms on bed movements could be seen from the isoconcentration plots.

7.1.3 Currents

The current data obtained from Station CM1 on the southern Sturgeon Bank indicated a flood direction toward true east and an ebb direction toward true west-northwest, Figure 17. A time series representation of the current velocity vector showed it always rotating in a clockwise direction with the tip describing an ellipse. The current flowed in the flood or ebb direction for the majority of the time, swinging quickly from one direction to the other around the time of slack water.

The current speeds at Station CM1 appeared to be very similar in ebb and flood directions during periods of spring tides. During neap tide conditions, the ebb currents were noticeably stronger than the flood currents.

The records obtained from CM1 displayed little influence of the Fraser River currents upon the tidal currents. Even very small high and low tides were enough to produce a current direction reversal from ebb to flood. A strong river influence would have induced a uni-directional flow with only a change in current speed signifying flood or ebb condition. The wind also appeared to have had little, if any, influence, on the current velocity at CM1 during the study period.

The current data obtained from Station CM2 on the northern Roberts Bank showed a flood current direction toward the true east and an ebb current direction toward the true southwest, Figure 18. At times of small flood tides, there was no change of current

direction to the east, but rather a diminuation of the southwest current. It appeared that the southwest current flow reversed to an easterly direction on the flood tide more readily with greater water depth at CM2 than with shallow depths, even if the difference between low and high tide heights (and hence the expected flood current speed) was low. The velocity vector describing the current ellipse during spring tides rotated in a clockwise direction. During neap tides, however, the vector swung clockwise from flood to ebb and counter-clockwise from ebb to flood.

A comparison of wind and current data from CM2 indicated that the tidal current flow could be influenced by the wind. On one occasion this influence took the form of a strong eastly wind strengthening the current flow in the westerly or ebb direction to the extent that a flow reversal to the flood direction did not occur as usual, but rather the westerly flow was attenuated. On another occasion, a strong westerly wind combined with a large spring flood tide to produce an unusually strong easterly current.

The average peak flow velocities for CM1 and CM2 were noted to be as follows:

		Ebb (m/sec)	Flood (m/sec)
CM1	Spring tide	.50	.50
	Neap tide	.30	.25
CM2	Spring tide	.80	.55
	Neap tide	.60	.40

A comparison of current profiles at the stations on Sturgeon Bank with the measurements at CM1 indicated close agreement with respect to maximum speeds and with direction, although Stations 2 and 3 had more northerly ebb flow directions than CM1. The current phase at Station 5 appeared to lead that at CM1 by 90° on the ebb but agreed closely with CM1 on the flood. The phase at Stations 2, 3, and 4 agreed with CM1.

The current profile at Stations 6 and 7 agreed quite well with the measurements at CM2 on Roberts Bank with respect to directions and phase, while the speeds at Station 6 were generally faster by 1½ times and the speeds at Station 7 were slower by half. The comparison of CM2 to Station 8 was quite poor, with no clear relation of speed. Also the

flood direction at Station 8 was NNW as opposed to E at CM2 and the ebb direction at Station 8 was WSW as opposed to SSW at CM2. The comparison of CM2 with Station 9 was likewise quite poor with the speed at Station 9 one-half that of CM2 on the ebb and greater than CM2 on the flood. The ebb directions were similar (SW and SSW) but the flood at Station 9 was NW to W while at CM2 it was mostly E.

7.1.4 Sand Ripples and Dunes

During each visit to the study stations observations were made of ripple and dune orientations, heights and wavelengths, as indicated in Figures 8 to 15. There was a considerable scatter of results but the following trends seemed evident:

i. Ripples - Stations were always visited at low water, i.e., after the ebbing tide. Observed ripple alignment was generally in the direction of the local ebb current.

ii. Dunes - Sturgeon Bank: The orthogonal direction of the dunes on Sturgeon Bank lay between SE/NW and ENE/WSW True bearing, i.e., dune wave crests ran approximately north to south. The orthogonal direction of the dunes agreed approximately with the general direction of the higher waves caused by westerly storms and with the flood and ebb tidal currents at stations 4 and 5. At stations 2 and 3 the dunes lined up with the direction of the westerly waves and easterly flood currents, but not with the northerly set of ebb tide currents observed at the sties on June 14.

iii. Dunes - Roberts Bank: Dune orientation at sites on Roberts Bank was more varied over the period of study than on Sturgeon Bank. This was consistent with the greater degree of sand movement indicated at Roberts Bank by the isoconcentration lines. Factors affecting variation in dune orientation may have been:

(a) variation in South Arm and Canoe Pass discharges;

(b) partial wave protection by the Steveston North Jetty; and

(c) a wider variation in wave refraction over Roberts Bank than Sturgeon Bank due to more pronounced surface irregularities.

7.1.5 Depth of Disturbance Rods

The variations of bed level as indicated by the four depth of disturbance rods set 15 m away from each station are shown in Appendix C. Apart from Stations 2 and 5 these showed the following clear trend; a rapid drop in apparent bed level as indicated by the washer height immediately after placement of the rods, followed by a period where the washer level remained reasonably constant. The reason for the sharp drop was not obvious, but was believed to result from sinking of the washer into the sand surface in response to the local disturbance of the rod. Vibrations of the rod in the tidal currents may have contributed to liquefaction of the sand, allowing the washer to sink. Taking account of the unexplained initial trend for the washer to sink and the small magnitude of subsequent movements, the data was considered inconclusive and not analyzed further.

7.1.6 Sediment Pans

A 35 cm square sediment collection pan was installed at Station 6 on June 18 and retrieved on June 20 when it was found to be up-ended and almost completely buried. It appeared obvious that the bedload transport rate at this site was too great for this type of measurement.

On June 22, the pan was deployed at Station 7 and examined 24 hours later. It contained a total of 1.4 kg of sand, one-third of which was in the section facing toward ENE. The sections facing SSE and NNW contained about one-quarter of the total while the section facing the WSW contained only one-sixth of the total. This indicated that the predominant bedload transport during this period was toward WSW. The isoconcentration lines indicated that the net movement at this station was generally towards the SSE.

The sediment pan was next placed at Station 9 on June 25 and retrieved 48 hours later. A total of 6 kg of sand was retrieved of which 35% was in the NNW sector, 28% in the WSW sector, 21% in the south-southeast sector, and 16% in the ENE sector. This indicated a predominant direction of SSE for the movement of bedload. This was consistent with movement indicated by the isoconcentration lines.

The sediment pan was lastly placed at Station 5 for a period of 48 hours starting on July 10. Of a total of 0.6 kg of sand in the pan, 39% was in the north sector, 27% in the east, 18% in the west, and 16% in the south. These results indicated a trend for the bedload to move mostly in a southerly direction as compared to the isoconcentration lines which indicated movement in a SE direction.

Comparing total quantities of sand collected in the pan, it appeared that Station 6 had the highest transport rate with Station 9 having the second highest transport rate. Stations 7 and 5 experienced the lowest transport rates of the locations studied..

8. DISCUSSION OF RESULTS

8.1 Analysis of Individual Stations

8.1.1 General

Laboratory tests on dyed sand samples at the start of the program indicated that leaching of dye from the tracer sand would be less than 4% per day in relatively still water. This was confirmed by analysis of the small contained control samples placed at each site and retreived during the field program. Laboratory tests of dye losses from sand agitated for over 30 minutes in seawater by a shaking machine showed that up to 70% of the dye might be removed from sand by abrasion with neighbouring grains.

Integration of the measured concentration values obtained in the field at each sampling location indicated that much of the tracer sand was unaccounted for. On average, there appeared to be about 90% loss of dye from the tracer sand within the first 48 hours and a further 50% loss over the next 15 days. A part of the dye loss may have been due to considerably more abrasion in the field than was experienced in the laboratory. Part of the apparent loss may also have been due to use of too large a sampling grid in the area of the station centre with consequent inaccuracies made in establishing the location and peak dyed sand concentration at the centroid of the remaining sand. Although much of the dye was unaccounted for in the surveys, calculated general transport rate at each station would not be greatly affected by the loss as the rates were based on movement of the apparent centroid of the recaptured sand.

8.1.2 Station 1

Studies at Station 1 were aimed primarily at establishing operating techniques. Complete grid sampling was not obtained. The site selected was on the exposed top of a 20 cm high by 60 m wide sand dune of approximately 40 m wave length lying in a NW-SE direction, Figure 5.

The data collected at Station 1 indicated that very little movement of tracer sand took place during the study period. Visual observations indicated a slight northeasterly movement of dyed sand during the first three days but negligible amounts of dyed sand

were picked up at distances of 5 m from the station centre. After 26 days, the centroid of dyed sand had shifted about 10 m to the east, probably as a result of a severe westerly storm which occurred 15 days after placement. Tracer sand movement at Station 1 appeared to be more affected by wave action during infrequent storms than by tidal current action during the study period.

A study of photogrammetric surveys of this area revealed that the size and position of the local dune fields were remarkably stable between 1967 and 1975 (Clague and Luternauer, 1982). Levings (1980) has noted, however, that the heights of individual dunes along the inner part of the North Arm Jetty can change by as much as 30 cm within a three month period during the winter.

8.1.3 Station 2

The isoconcentration lines, Figure 8, showed no movement of bed material at this station. A deposit of fine clayey silt was observed over the area on the first return visit after placement of the dyed sand. The silt was probably brought down by the Fraser River and effectively buried the station until 11 days after placement at which time the dyed sand was observed still in place on the surface. The observed silt covering at the centre post was not consistent with the peripheral depth of disturbance rods which indicated net degradation over the first few days and a net deposition over the site by the 11th day after placement. This possibly resulted from passage of a moving bedform over the site. The lack of sediment movement indicated by the isoconcentration plots agreed with theoretical findings of previous WCHL studies that there is little surface movement occurring in this area. This information will be of value for the design of the proposed new Iona Sewage Outfall pipe.

Luternauer and Murray (1973) suggested that although the Middle Arm carries only 5% of the total river discharge, it appears to be enough to supply a significant amount of sediment (well sorted, median sand from 0.25 mm to 0.50 mm) to Sturgeon Bank and possibly also to the adjacent upper foreslope. The supply of sediment is enough to cause a slight annual advancement of the foreslope.

8.1.4 Station 3

The isoconcentration lines, Figure 9, showed a very limited movement of bed material towards the NNE between the placement date, June 8, and the second sample date, June 10. Between June 10 and June 19 the NNE movement either ceased or reversed and there appeared to be a small movement to the ESE. Between June 19 and June 24, the NNE movement appeared to be reestablished.

The predominant wind directions at this station were E to SE and W to SW. Between June 10 and 14, a WNW storm occurred which could account for the ESE movement during the period although the storm showed no noticeable effect on current directions and speeds at CM1.

A vector addition of the observed flood and ebb currents at both Station CM 1 and Station 3 gave a general N movement which could account for bed movement in this direction.

According to the depth of disturbance rods, between June 8 and June 9 there was a fall in bed level of about 1 cm. Bed level then remained constant until June 19 when it was measured at a maximum of 3 cm below the original level. The periods of change in bed level and of dyed sand movement to the NNE appeared to correspond to the periods of highest tides during the two week period. No NNE movement or change in bed level was noted over the period of lower tidal range between June 10 - 19. The NNE movement direction corresponded to the net residual tidal velocity direction component found after analysis of the field current measurements.

During sampling visits to the station free dye was observed, indicating that bed movement was very limited. Little, if any change was noticed in the shallow sand waves, or dunes in the area. They had an average height of 4 cm and wavelength of 2 m. Their orthogonals were aligned toward the ESE, possibly as a result of winter storms from the WNW.

8.1.5 Station 4

The isoconcentration charts, Figure 10, showed a general but limited movement to the ENE between July 8 to 18 with a "spread" in the north to SE directions. Between July 18 and July 23 there was a marked shift to the E. The movement of bed material was contrary to what might have been expected at a station so close to the Fraser River channel. A westerly movement due to high river flows would have seemed more likely than the observed ENE movement.

A vector addition of the ebb and flood currents may account for the limited NE movement of the bed. Actual directions of ebb and flood could account for the NW/SE spread of the dyed sand. Despite the close proximity of Station 4 and CM1 to the Fraser River channel, the current metering results showed very little influence of Fraser River flow on currents in this area. It appeared that sand movement at Station 4 was primarily dependent upon the incoming flood currents with a northerly component added by the ebb tide and perhaps some shoreward movement due to wave action at low tide.

The predominant wind directions were easterly and westerly with significant storms from the ESE and the WSW occurring between July 13 to 15. SW winds reached 19 km/hr just before low tide on the second sampling day of July 10 and a westerly storm occurred before and during low tide on the day of the third sampling visit, July 18. However, it is not believed that the ENE movement could be accounted for by deep water storm waves from the SW or WSW due to protection by Steveston Jetty. A 15 km/hr WSW wind at low tide on July 21 was the only source of waves possibly causing the marked E shift of the isoconcentration lines between July 18 and July 23. However, low tide levels were exceptionally low between July 18 to 23 and tidal flows were considered more likely than wave action to have caused the easterly sand movement.

The depth of disturbance rods showed a steady erosion of bed material from the station.

8.1.6 Station 5

The isoconcentration plots for this station convey only a limited amount of information, Figure 11. The measured concentrations on July 10 were low, possibly due to

sediment deposition at the station. The scheduled July 18 samples were not taken due to operational difficulties. The July 8 sampling showed a limited movement of bed material to the SW and SSW but by July 23 the movement was markedly ESE. These findings were consistent with the sand wave alignment observations taken during the site visits.

Ebb and flood currents were almost opposite in direction, flowing to the west on the ebb and to the east on the flood. It was not clear in which direction the tidal speed was greatest. Ebb tidal flow probably induced the initial movement to the SW.

The westerly storm occurring before and during low tide on July 18 was probably the main cause of the net ESE movement which occurred between July 10 and July 23. The effect of wave reflection from Steveston Jetty may have influenced bed movement at this station.

8.1.7 Station 6

The isoconcentration charts showed a marked and progressive movement of bed material to the SSW, Figure 12. Observations showed that some of the tracer sand had passed the southern edge of the grid by the first sampling day on June 18. The SSW movement of the sand continued throughout the study period. A southerly bulge to the plotted isoconcentration lines was due to local effect of a nearby surface drainage channel.

Wind direction between June 18 and June 25 was varied and generally light but between June 25 and July 5 was stronger and predominantly east to SE. The station was shielded by Steveston Jetty and the local shoreline from all except south or SW storms. Storm waves could not have produced the sand movement in a SSW direction.

Flood and ebb currents were almost identical in direction at this site during the period of river freshet discharge. Flood currents were measured between south to SSE and ebb currents were measured between S and SSW. Ebb currents, reinforced by river flow were stronger than flood currents. The tidal and river currents at the site accounted for the movement of bed material.

The depth of disturbance rods showed an apparent rapid fall in bed level of between 1 cm and 4 cm between June 18 and June 20. The rate of bed level fall was either reduced or reversed by June 26 and the bed level remained fairly constant thereafter.

8.1.8 Station 7

The isoconcentration charts showed a sustained movement of bed material to the S, Figure 13. Between tracer sand placement on June 18 and June 22 there appeared to be a movement to the south and SSW. Movement between June 22 to 26 was to the SE but the southerly motion regressed slightly and a general east-west spreading occurred between June 26 and July 5.

Between June 10 and June 25 winds were generally light and varied. After June 25 wind directions were generally easterly with a SSE storm occurring at low tide on July 3.

Current metering at Station 7 showed that ebb flows to the SW were considerably stronger than flood flows towards the E. Current metering at CM2, very close to Station 7, showed a predominance of higher velocities in the SSW direction and, during neap tides, a marked preference for flow in the SSW direction. The combined effects of ebb and flood flows during low spring tides appeared to be the major factor in the general SSE migration of tracer. The SSE storm near low tide on July 3 probably caused the northerly regression and east-west spreading noted between June 26 to July 5.

The depth of disturbance rods showed a rapid drop of between 2 to 3 cm in bed level between June 18 and June 26. Thereafter the bed level remained reasonably constant.

8.1.9 Station 8

The isoconcentration plots showed a general and sustained movement of bed material towards the WSW, Figure 14. Between June 25 and July 4 there appeared to be a temporary check to the WSW movement together with a slight shift N of the isoconcentration lines.

Between tracer sand placement on June 21 and June 25 winds were light and variable. Between June 25 and July 9 wind directions were E to SE with one significant storm from the SSE occurring just before July 4. At low tide, refraction of the deep water waves associated with this storm to Station 8 gave wave orthogonals in an approximately northerly direction. This storm probably caused the northerly shift of the dyed sand.

Current metering at CM2 showed a predominance of higher velocities in the SSW direction and, during the neap tide period between June 25 and July 4, a marked preference for flow in the SSW direction. Current metering at Station 8 showed that WSW going ebb tide currents were stronger, but of shorter duration than NNE going flood currents. These WSW ebb currents were considered to account for the overall WSW movement of bed material.

The depth of disturbance rods showed only a very small change in bed level at this station, the general level falling by between 1 and 2 cm.

8.1.10 Station 9

The isoconcentration charts showed a general and sustained southerly movement of bed material, Figure 15. Between June 25 and July 4 there was a marked migration of bed material towards the W which was not sustained thereafter.

There was only a limited amount of current metering information available for this station as CM2 was too far away to be directly applicable and readings at the station itself were few. However, tidal flow has been found from earlier studies to be predominantly onshore-offshore, with the ebb tide current to the SW and the flood current to the NE.

General wind and wave directions at this site were the same as for Station 8. The shift of tracer sand movement to the west and, possibly NW, noted on July 4, may have resulted from the strong SE storm at low tide on July 3.

The southerly movement of bed material was probably due to a combination of ebb currents to the SW and the local influence of the deep channel to the SE of the station.

Site reports indicated that on ebb tides, well established dendritic drainage channels carried large amounts of bed load to this channel.

An examination of aerial photographs of this area in 1967 and in 1978 indicated that the major outflow from Canoe Pass across tidal flats underwent avulsion, or a change of channels from a more northerly channel to the present more southerly channel. At the same time the channel that sweeps by the Station 9 location appears to have intensified its flow to the sea.

The depth of disturbance rods showed a fall in bed level of between 2 and 4 cm between June 21 and June 23. Thereafter the bed level remained constant.

8.2 Bedload Transport Computations

8.2.1 Methods of Assessing Transport

The dispersion or movement of a tracer material such as dyed sand from a localized, concentrated source may be described by two parameters. The first is the advection or net rate of movement in a dominant direction of the centroid of the tracer mass. The second is the diffusion or spreading out of the tracer material from around its centroid.

Advection, or net transport of sand is due to water velocities above a threshold speed and in a preferred or net direction. The water speed must be above a threshold value in order for there to be enough shear stress on the sand particles to start them in motion. The process of diffusion is a turbulent or random process of "mixing" in response to nature's tendency toward isotropy. Although this process is characterized as being random, it is not always equal in magnitude in all directions. A sand bed subjected to a colinear flood and ebb current would be expected to diffuse more along the current axis than along an axis perpendicular to the current.

Calculations were made from the various data sets to determine values of advection, or bedload transport during the study. Three different methods were used:

i. dispersion calculations based on the tracer sand concentration contours for each station;

ii. transport measurements from the Arnhem bedload sampler at Station 6; and

iii. a calculated transport by the Ackers-White method at Stations 6 and 7.

8.2.2 Dispersion Calculations from Isoconcentration Contours

Although there are many methods to determine the advection and diffusion parameters of tracer material, it was decided that a spatial integration method was best suited to the data sets acquired during this study. In this method, a distribution curve was fitted by eye through the observed tracer concentration data along the two principal axes of the dispersion cloud. The major principal axis was defined as the line joining the more separated points on the outermost isoconcentration contour and passing through the point of highest concentration in the tracer cloud. The minor principal axis was defined to be normal to the major axis and to also pass through the point of maximum concentration. The zeroth, first, and second moments of area (M_0, M_1, M_2 respectively) were calculated from the fitted distribution in the usual manner.

$$M_0 = \int_{-\infty}^{\infty} c(x,t)\,dx$$

$$M_1 = \int_{-\infty}^{\infty} xc(x,t)\,dx$$

$$M_2 = \int_{-\infty}^{\infty} x^2 c(x,t)\,dx$$

where c(x,t) is the concentration of tracer sand as a function of distance along the principal axes and time.

The advection of the tracer sand was computed from the time progression of the centroid of the concentration distribution curves along their respective axes during the sampling period for each station. That is,

$$\text{advection} = \frac{d}{dt}\left(\frac{M_1}{M_0}\right) = \frac{d\ell}{dt}$$

where ℓ is a length along a principal axis defining the centroid.

The diffusion of the tracer sand was defined as the time rate of change of the variance of the concentration distribution along the principal axes. This was calculated from the same data plots and over the same sampling periods as the advection in the following manner:

$$\text{diffusion} = \frac{d}{dt}\left[\frac{M_2}{M_o} - \left(\frac{M_1}{M_o}\right)^2\right] = \frac{d}{dt}\,\sigma 2$$

where $\sigma 2$ is the variance.

The results of the advection and diffusion calculations along each of the principal axes are indicated in Table III for each station except 1 and 2 which showed virtually no dispersion. Values are given for the time periods between each sampling visit. The first set of values for each station are for the time period between the initial placement of tracer sand and the first sampling visit. During this time the majority of the tracer sand, or at least the fluorescent dye, disappeared from the study area, possibly due to abrasion. Consequently the initial values of advection and diffusion from the placement date must be regarded with caution. The net values of advection and diffusion for each station from the first sampling date to the last are shown in Figure 19.

The average advection values for all the stations were less than 0.4 metres/day. The largest advective value was determined at Station 9. Apart from Stations 1 and 2, Stations 3 and 5 had the smallest advection at less than 0.1 metres/day.

Stations 1 and 2 showed the lowest advection rates. This finding was consistent with observations of air photos taken between 1949-78 which showed that surface features on the northern part of Sturgeon Bank did not significantly change location during that period. Advection at Station 1 appeared primarily due to wave transport with very little movement due to currents. The average transport rate at that station is therefore likely to vary with storm frequency and could not be reliably assessed during this relatively short study. Average diffusion rates ranged from 4.5 m^2/day at Station 6 and 3.3 m^2/day at Station 8 down to Station 3 with 0.3 m^2/day. The diffusion was not in general equal in

magnitude in all directions but tended to be greatest along the axes of predominant tidal currents.

Figure 20 illustrates the time progression of section values of tracer sand concentration along the major and minor principal axes at Station 6. The minor axis sections did not show any spreading or movement of the tracer sand mass. The major axis sections clearly showed advection of the tracer sand mass and a large amount of "spreading out" of diffusion along the axis.

Bedload transport calculations based on two dimensional tracer sand contours require an assumption concerning depth of bedload movement. In the case of Station 6, depth profiles generally indicated that the active bedload was within the top 0.12 m although the first depth profile on June 22 had indicated that some dyed sand mixed down to a depth of about 0.20 m. If we consider 0.12 m to be the average thickness of the active bedload, then the average transport at Station 6 can be calculated as about 0.03 m^3/day per metre width.

8.2.3 Transport Measurements from the Bedload Sampler

The measured results from the bedload sampler are indicated in Table IV. Station 6 was the only location where an appreciable quantity of sand was obtained. The only other site where the current was strong enough during sampling to move bedload into the sampler trap was in a fast-flowing channel near Station 4. Based on comparison of measured currents at Station 6 and at CM2, an approximate calculation of bedload transport rate was made from the measured values of sample weight, duration of sampling interval, and length of time that current velocities were expected to be above the calculated threshold velocity. The tides at the time of measurement at Station 6 were in the transition period between spring and neap, so the results may be assumed to be an average over the fortnightly tidal range cycle. Taking into account a sampling efficiency of 70% for the Arnhem sampler (Meyer-Peter, 1937), an average bedload transport of 1.4 m^3 day per metre width was estimated for Station 6.

8.2.4 Calculated Transport by Ackers-White Method

The Ackers-White equations were developed for the calculation of bedload transport with knowledge of water velocities, depth, and grain size. The equations involved three functions: mobility number, size, and transport which were dependent upon a series of five coefficients. The three dimensionless functions may be determined if the following conditions are known:

i. threshold conditions - velocity versus depth relationship;

ii. average transport conditions above threshold, i.e., mean velocity and associated depth;

iii. shear velocity at threshold with mean conditions.

Using the current velocity relationship determined between CM2 and Station 6, the time history of the flow conditions at Station 6 was produced and the average bedload transport calculated using the Ackers-White equations. The results indicated that the ebb currents moved about 0.42 m^3/day of bedload per unit width and the flood current moved about 0.01 m^3/day. The net movement, then would be about 0.41 m^3/day in the ebb direction.

A similar calculation was done for Station 7, but the calculations indicated that the current velocities were never large enough to move any sand.

It should be noted, in viewing these results, that the Ackers-White equations were developed for steady, uniform flow in open channels. By contrast, conditions on the Fraser foreshore were extremely variable, both in time and space. Factors that affect bedload movement on the foreshore but which are not considered in the Ackers-White formulation include:

i. currents vary with tidal phase (ebb and flood), tidal range (neap and spring), depth and location;

ii. depth of water varies with the tidal cycle; and

iii. wave action, which is variable in direction and intensity, may influence shear stress at the bed.

8.3 Discussion

8.3.1 Sturgeon Bank

Observations from Sections 8.1 and 8.2 on net advection rates are compared in Table V in order to establish the relative importance of tidal currents and wave action on sand movement. The comparison is biased toward current effects by the study being undertaken during extreme spring tides combined with Fraser River freshet at a time of the year when storm frequency is low. However the extreme spring tides also produced bery shallow water levels over the study sties and thereby rendered them more susceptible to movement by wave action than would normally be the case.

Movement of bed material at the Sturgeon Bank sites was very limited during the test period. At Station 1, minor sand movement to the NE due to current action was observed in the first few days but the only significant motion was towards the east due probably to storm action. No siginificant motion was found at Station 2.

Movement at both Stations 3 and 4 was inshore with a northerly component due probably to the net vectorial action of ebb and flood tide currents. No effect was apparent on sand movement due to flow through the Steveston Jetty opening at Garry Point. Site 3 may have experienced some minor easterly transport of sand due to wave action from storms at low spring tides but Site 4 was unlikely to have experienced any wave effects.

Movement at Site 5 appeared primarily due to wave action occurring at low spring tide with tidal currents producing only minor effects. Apart from Station 2 where no motion was observed, all of the more exposed sites on Sturgeon Bank evidenced easterly sand movement due to wave action occurring near low tide. The amount of easterly movement from these stations on an annual basis however would depend on the frequency of severe storms occurring at such few times as the spring tides were as low as occurred during the study period.

The influence of river flow on bed movement appeared to be minimal. The fact that Station 2 was buried under silt brought down by the river indicated that fluvial sediments were transported across the bank but that currents over the bank in that area were slow.

8.3.2 Roberts Bank

Bed movement on Roberts Bank was clearly more influenced by Fraser River flow than on Sturgeon Bank. However, net bed movement was not exactly in the direction of the local ebb current but was influenced by local topography. The directions of local ebb currents at various stations were affected by the direction or orientation of adjacent drainage channels carrying river flows across the bank. As the tidal level fell, the ebb flow direction deviated from that of the general ebb to one dictated by localized drainage.

At Station 6, bed movement was determined solely by tidal and river currents. Waves did not influence this station. The effect of wave induced currents at other stations on the bank was secondary to tidal and river currents. Sand movement was generally in a southerly or offshore direction. At Stations 7, 8 and 9 a minor effect on sand movement was noted due to wave action produced during a SSE storm occurring before and during low tide on July 3.

8.3.3 Transport Rate at Station 6

The calculations made for Station 6 using the 3 methods discussed in Section 8.2 gave the following results for net bedload transport over the study periods:

calculated from isoconcentration coutours - 0.03 m^3/day per metre width
calculated from Arnhem bedload sampler measurements - 1.4 m^3/day per metre width
calculated from Ackers-White formulation - 0.4 m^3/day per metre width

These results are considered in reasonable agreement with each other with regard to the major assumptions made in assessing and applying the field data. The field tracer observations indicated a very much lower average transport rate than was calculated on

the basis of current velocities. Based on geometric averaging of the highest and lowest values, the results indicated a probable mean transport rate of between 0.1 to 0.4 m^3/day per metre width of bedload transport at Station 6 during the study period.

9. MATHEMATICAL MODEL

9.1 Dispersion Models

A computer study was made into the feasibility of mathematically modelling the sand dispersion process across the foreshore. The study initially assessed an existing two dimensional dispersion model described by de Vries (1973) as suitable for transport under uni-directional currents. When this was not found suitable to describe transport in the complex hydrodynamic conditions at the mouth of the Fraser River, a new Fraser Foreshore dispersion model was developed and calibrated using the field observations, Appendix D.

The development of the mathematical dispersion model involved two phases:

i. the assessment of advection and diffusion parameters of the tracer material in its dispersive environment, and

ii. the numerical representation of the dispersion process.

Values of advection and diffusion for each station are described in section 8.2. These were used as input parameters in the numerical model developed for this study.

9.2 The de Vries Dispersion Model

de Vries (1973) presented a series of mathematical models for one-dimensional and two-dimensional dispersion of bed load material. These models were analytical solutions of the advection - diffusion equation based on the conservation of a scalar variable. For the two-dimensional case, this equation was written as follows:

$$\frac{\partial c}{\partial t} - D_x \frac{\partial^2 c}{\partial x^2} - D_y \frac{\partial^2 c}{\partial y^2} + W_x \frac{\partial c}{\partial x} + W_y \frac{\partial c}{\partial y} = 0$$

where c = concentration of the tracer material

D_x, D_y = coefficient of diffusion in the x and y directions respectively.

W_x, W_y = advection of the tracer material in the x and y directions respectively.

This formulation assumed no losses of tracer material through sedimentation or other processes. de Vries further simplified his problem by assuming uni-directional currents with no lateral advection.

The de Vries model of bedload transport was considered to be much too constrained for application to the Fraser foreshore with its multi-directional currents and hence multi-directional advection and diffusion. Thus, it was decided to extend de Vries' formulation to make it applicable to the present study area and to solve the differential equation using numerical rather than analytical techniques.

9.3 Fraser Foreshore Dispersion Model

A mathematical model suitable for application to the Fraser foreshore was developed from the two-dimensional equation above. Instead of introducing de Vries' simplifying assumptions of unidirectional currents and no lateral advection, however, allowance was made for a variation of D_x, D_y, W_x and W_y in both time and space along both the x and y directions. A sink term was also included to account for tracer sand that was lost to the field sampling procedure due to sedimentation or transport out of the study area.

A numerical scheme was established to solve the resulting differential equation. The numerical operator used for the time rate of change term was as follows:

$$\frac{\partial c}{\partial t} = \frac{c(t+1) - c(t)}{\Delta t} + O(\Delta t)$$

and the operator for the diffusion term:

$$\frac{\partial^2 c}{\partial l^2} = \frac{c(\ell+1) - 2c(\ell) + c(\ell-1)}{\Delta \ell^2} + O(\Delta x)^2$$

The operator associated with advection was chosen depending upon the location of the current computational cell. This location was differentiated between the four quadrants defined by the x and y axes, corner cells, and boundary cells. The operator was either fully forward, fully backward, or partly forward and partly backward in x and y.

The program was run using the calculated advection and dispersion rates shown in Table III to reproduce the tracer isoconcentration patterns determined for Station 6 from the field studies. Results of various simulation runs using the field data from Station 6 indicated the following:

i. the time evaluation of the peak tracer concentration at the placement point was acceptably reproduced by the numerical model when values of D and W from the field data were used as inputs to the program,

ii. the evaluation of the spatial concentration gradients along the principal axes of the tracer cloud were not well reproduced due to the mathematical model giving no consideration to dye losses from the tracer sand.

The numerical model results showed tracer sand concentration values should have been much higher in the outer regions of the tracer cloud than the observed values. The computer model did not consider any dye losses due to abrasion or leaching. It is quite likely that a more representative simulation could be run using as starting concentrations those measured during the first sampling visit to the station rather than the initial placement values. Due to time constraints this exercise was not carried out. However operation of the computer program indicated that the overall processes could be mathematically modelled if suitable field results were available for program input.

An annotated listing of the computer program is given in Appendix D.

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REFERENCES

1. Carter, H.H., 1974. The measurement of rhodamine tracers in natural systems by fluorescence. Rapports et Proces-Verbaux des Reunions, Volume 167: Physical Processes Responsible for Dispersal of Pollutants in the Sea. Edited by G. Kullenberg and J.W. Talbot. Conseil International Pour L'Exploration de la Mer.

2. Clague, J.J. and Luternauer, J.L., 1982. Field Excursion Guide Book, Excursion 30A: Late Quaternary Sedimentary Environments, Southwestern British Columbia. International Association of Sedimentologists. Eleventh International Congress on Sedimentology, McMaster University, Hamilton, Ontario, Aug. 22-27, 1982.

3. Luternauer, J.L. and Murray, J.W., 1973. Sedimentation on the western delta-front of the Fraser River, British Columbia. Can. J. Earth Sci., V. 10, no. 11, p. 1642-1663.

4. Mathews, W.H., and Shepard, F.P., 1962. Sedimentation of Fraser River delta, British Columbia (includes Discussion by K. Terzaghi). Am. Assoc. Pet. Geol., Bull., V. 46, p. 1416-1443.

5. Meyer-Peter, E., 1937. Discussion of "Appareil pour le jangeage du debit solide entraine sur le fond du cours d'eau (An instrument for the measurement of bedload in rivers.)": Berlin, International Assoc. Hydraulic Structures Research, 1st meeting, Berlin 1937, p. 109-110, Translation, Iowa University, Inst. Hydraulic Research.

6. Russell, R.C.H., 1960. The use of fluorescent tracers for measurement of littoral drift. Proc. 7th International Conference on Coastal Engineering, pp. 418-444 A.S.C.E., New York.

7. Tabata, S., Giovando, L.F., and Devlin, D., 1971. Current velocities in the vicinity of the Greater Vancouver Sewerage and Drainage District's Iona Island outfall - 1968. Fish. Res. Bd. Can., Tech. Rep. No. 263, 110 p.

REFERENCES

8. Tamburi, A. and Hay, D., 1978. An Introduction to River Mechanics and the Lower Fraser River. Marine and Civil Engineering Section, Department of Public Works, Canada. 72 p.

9. Teleki, P.G., 1966. Fluorescent Sand Tracers. Journal of Sedimentary Petrology, June 1966, Vol. 36, No. 2, pp. 468-485.

10. Thomson, R.E., 1981. Oceanography of the British Columbia Coast. Canadian Special Publication of Fisheries and Aquatic Sciences 56: 291 p.

11. U.S. Army Coastal Engineering Research Center, 1981. Coastal Engineering Technical Notes I-5, I-6, and I-7.

12. Western Canada Hydraulic Laboratories, 1979. A Pilot Sand Tracing Study on the Fraser Foreshore. A report for the Department of Supply and Services, Canada.

TABLES

TABLE I

DEEP WATER HINDCAST WAVES

Dates	Direction	Duration (hours)	Mean Wind Speed (km/hr)	Fetch Length (km)	Wave Height (m)	Wave Period (sec)
May 16	SE	9	15.4	22.4	0.35	2.3
May 17	SE	5	16.2	22.4	0.35	2.3
May 21-22	WNW	5	24.0	37.4	0.70	3.2
May 24	W	2	29.0	25.6	0.79	3.5
May 25	W	9	49.7	25.6	1.43	4.7
May 25	W	6	33.5	25.6	0.87	3.7
May 25-26	W	16	30.0	25.6	0.79	3.5
May 26	W	9	34.2	25.6	0.87	3.7
May 28	W	4	21.8	25.6	0.49	2.8
May 31	WNW	12	18.8	37.4	0.46	2.7
June 11	WNW	4	19.5	37.4	0.43	2.6
June 12	SE	4	24.0	22.4	0.58	3.0
June 17	WNW	16	20.7	37.4	0.53	2.9
June 18	WNW	8	20.0	37.4	0.53	2.9
June 27	WNW	2	22.5	37.4	0.37	2.4
June 28	W	8	23.1	25.6	0.56	3.0
July 3	SSE	15	22.1	35.2	0.64	3.2
July 7	SSE	3	20.7	35.2	0.41	2.5
July 13-14	WSW	23	23.1	21.2	0.50	2.9
July 15	SW	6	21.0	21.2	0.46	2.7
July 18	W	8	21.3	25.6	0.50	2.8
July 23	W	9	21.9	25.6	0.53	2.9

TABLE II

SHALLOW WATER HINDCAST WAVES

Dates	Direction	Duration (Hours)	Mean Wind (km/hr)	Fetch Length (km)	Mean Water Depth (m)	Wave Height (m)	Wave Period (sec)
May 10-11	E	12	18.8	9.2	2.1	0.2	1.8
June 1	ESE	7	26.6	9.4	2.1	0.3	2.1
June 1	ESE	8	16.6	9.4	1.5	0.2	1.7
June 12	ESE	7	17.1	9.4	2.1	0.2	1.8
June 13	E	8	19.1	9.2	2.4	0.2	1.9
June 25	E	7	20.7	9.2	1.2	0.2	1.8
June 30	E	19	19.6	19.2	2.4	0.2	1.9
July 1	ESE	9	15.1	9.4	1.8	0.2	1.6
July 5	SE	5	19.8	22.4	2.4	0.3	2.1
July 7	E	2	19.0	9.2	1.5	0.2	1.8
July 13	ESE	13	17.0	9.4	1.2	0.2	1.7
July 15	E	4	20.8	9.2	1.8	0.2	1.9
July 19	E	5	21.8	9.2	1.8	0.3	2.0
July 19	E	3	19.0	9.2	1.8	0.2	1.8
July 20-21	E	9	15.7	9.2	3.0	0.2	1.8

TABLE III
ADVECTION AND DIFFUSION FROM CONCENTRATION CONTOURS

Station	Time Interval	Axes Orientation		Advection (m/day)		Diffusion (m^2/day)	
		+Y	+X	W_y	W_x	D_y	D_x
3	June 8-June 9	NE	SE	4.38	-0.04	-3.45	0.15
	June 9-June 10			-3.17	0.02	4.39	0.00
	June 10-June 19			-0.03	0.06	0.68	0.20
	June 19-June 24			0.20	-0.05	-0.37	0.35
Avg.	June 10-June 24			0.06	0.02	.31	0.26
4	July 6-July 8	NE	SE	0.17	0.37	0.83	0.95
	July 8-July 10			-0.41	-0.02	0.53	0.06
	July 10-July 18			0.46	0.11	2.36	0.58
	July 18-July 23			0.42	-0.40	-1.12	2.23
Avg.	July 8-July 23			0.30	0.09	0.71	1.02
5	July 6-July 8	WSW	SSE	0.10	-0.15	0.65	0.23
	July 8-July 10			-0.16	0.24	-0.34	0.23
	July 10-July 23			-0.05	0.05	0.36	0.35
Avg.	July 8-July 23			-0.07	0.08	0.32	0.34
6	June 18-June 20	SSW	ESE	1.66	0.00	12.82	0.69
	June 20-June 22			2.32	-0.14	16.15	0.02
	June 22-June 26			0.62	0.12	3.61	-0.07
	June 26-July 5			-0.17	-0.01	2.07	0.00
Avg.	June 20-July 5			0.26	0.01	4.48	-0.014

TABLE III (Continued)
ADVECTION AND DIFFUSION FROM CONCENTRATION CONTOURS

Station	Time Interval	Axes Orientation		Advection (m/day)		Diffusion (m^2/day)	
		+Y	+X	W_y	W_x	D_y	D_x
7	June 18-June 21	S	E	0.65	-0.03	9.53	1.23
	June 21-June 22			0.04	-0.11	1.07	-0.95
	June 22-June 26			0.51	0.57	-0.95	3.09
	June 26-July 5			-0.06	-0.13	1.10	0.64
Avg.	June 21-July 5			0.17	0.08	0.45	0.64
8	June 21-June 23	WSW	SSE	-0.10	0.08	0.47	0.32
	June 23-June 25			1.99	0.33	18.51	1.35
	June 25-July 4			-0.39	-0.08	-3.35	-0.26
	July 4-July 9			0.65	0.07	8.50	0.83
Avg.	June 23-July 9			0.25	0.02	3.27	0.30
9	June 21-June 23	S	E	1.53	0.12	9.61	0.81
	June 23-June 25			1.59	0.24	14.21	7.01
	June 25-July 4			0.20	-0.06	1.05	-0.56
	July 4-July 9			0.54	0.03	-3.86	0.50
Avg.	June 23-July 9			0.35	0.01	1.26	0.76

NOTE: Isoconcentration plots for Stations 1 and 2 showed insufficient results for mathematical analysis at these sites.

TABLE IV
BEDLOAD SAMPLER RESULTS

STATION 6 - 27 June 1982

Time Interval	Current Speed m/sec	Dry Sample Weight gm	Transport Rate gm/min
0924 - 0939	0.55	25.1	1.7
1103 - 1118	0.62	662.6	44.2
1201 - 1216	0.64	730.0	48.7
1437 - 1442	0.76	161.1	32.2

STATION 4 (Channel near station) - 22 July, 1982

Time Interval	Current Speed m/sec	Dry Sample Weight gm	Transport Rate gm/min
1015 - 1045	0.52	101.4	3.4

TABLE V
PROBABLE BED TRANSPORT FACTORS

Station	Net Advection Rate		Movement due to Waves	Movement due to Tidal Currents
	m^2/d	Dir.		
1	-	E	*Wave movement to E	Slight NE movement due to flood flow
2	-	-	-	-
3	0.1	ENE	*Wave movement to E	Northerly movement from combined ebb/flood vector
4	0.3	ENE	-	*Flood currents move to east with northerly component from combined flood and ebb flows.
5	0.1	ESE	*Wave movement to east	Ebb currents to SW.
6	0.3	SSW	-	*Combined ebb and river flow.
7	0.2	SSE	E movement from low tide storms	*Ebb currents to S and SW. Flood flows to E.
8	0.3	WSW	Minor effect of S storm	*Ebb flow to WSW dominates
9	0.4	S	Minor effect of S storm	*Southerly ebb flow dominates.

Note: * indicates the apparent prime factor in sediment movement during the study program.

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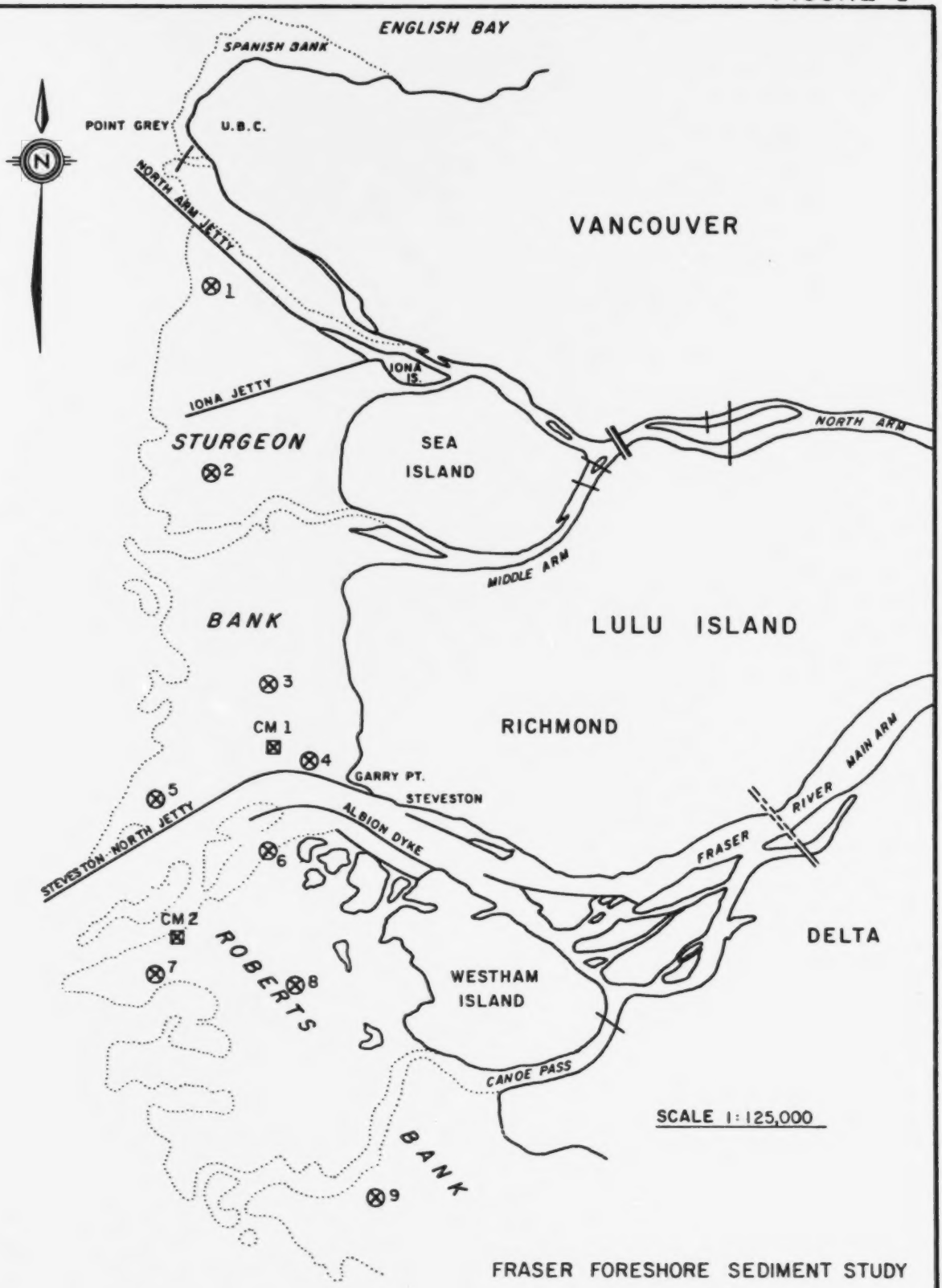
FIGURES

FIGURE 1



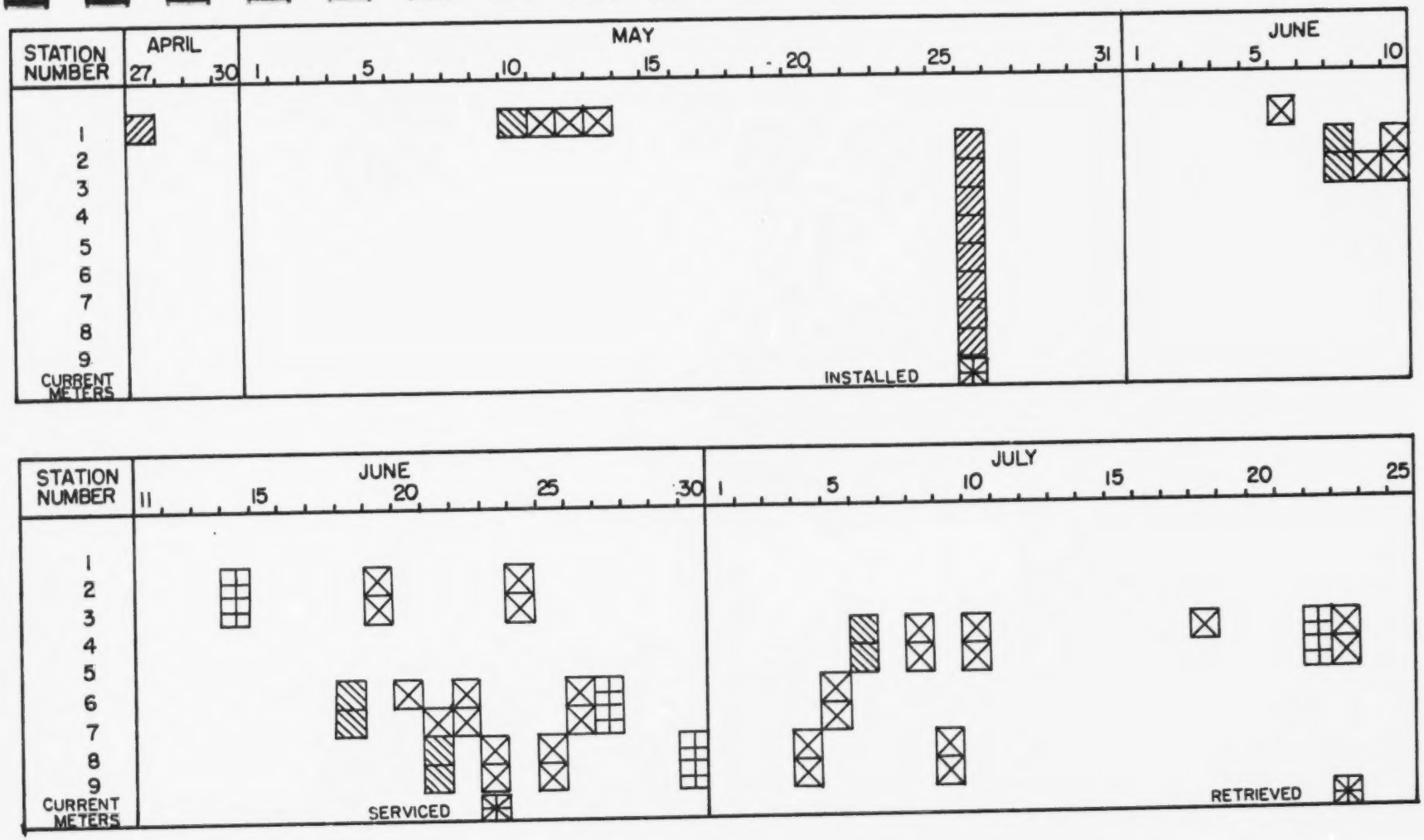
FRASER FORESHORE SEDIMENT STUDY

⊗ — FORESHORE STUDY STATIONS.
⊠ — CONTINUOUS CURRENT METER LOCATIONS.

FORESHORE PLAN WITH STUDY STATIONS

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

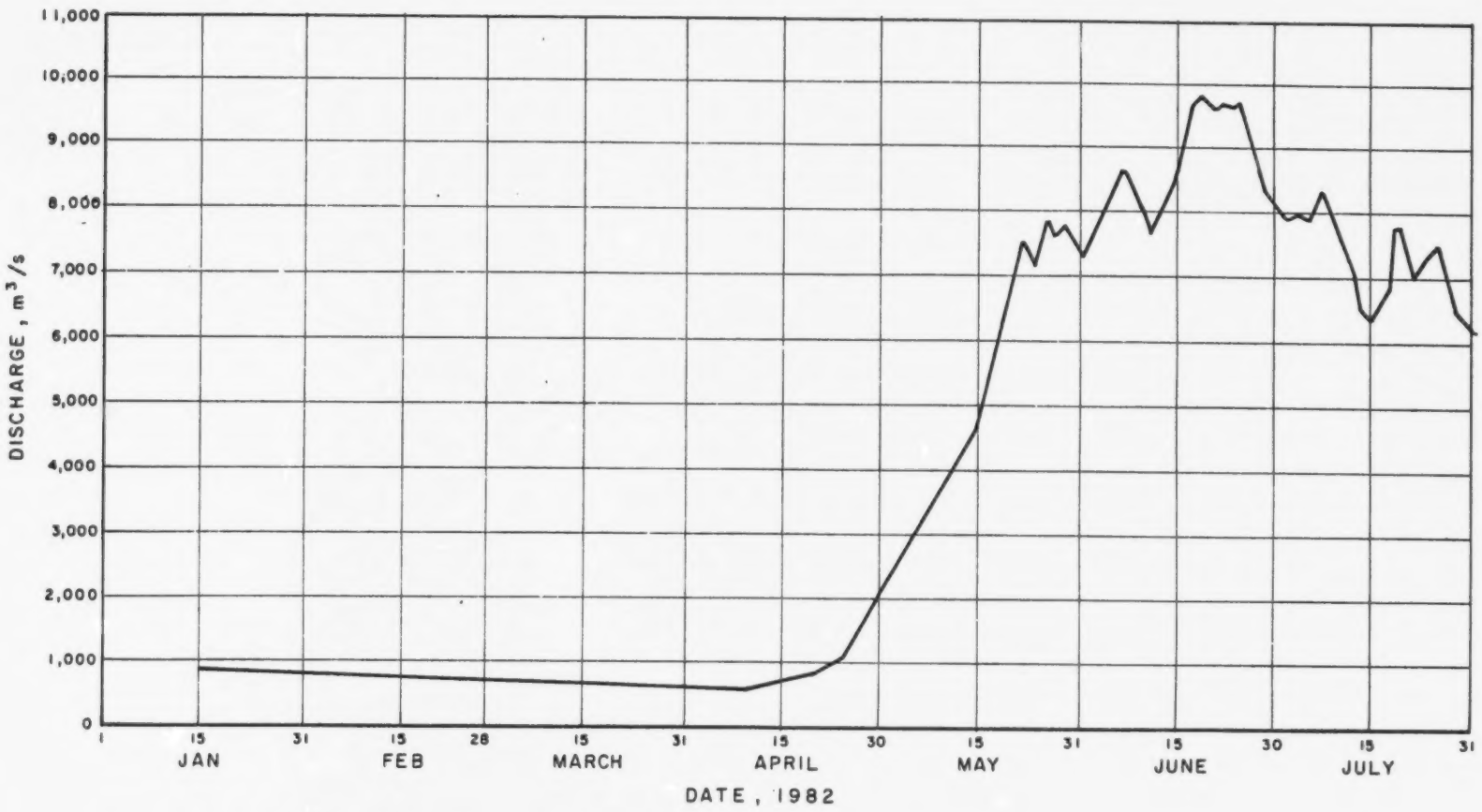
bcil 6639A-WCH



FRASER FORESHORE SEDIMENT STUDY

FIGURE 2

SCHEDULE OF COMPLETED FIELD WORK



NOTE: ALL DISCHARGES RECORDED AT HOPE.
DISCHARGES AFTER MAY 17 ARE DAILY 8:00 A.M. VALUES.

DISCHARGES BEFORE MAY 17 ARE MEAN MONTHLY VALUES.
ALL DISCHARGES SUBJECT TO REVISION BY WATER SURVEYS OF CANADA.

FRASER FORESHORE SEDIMENT STUDY

1982 FRASER RIVER DISCHARGES

FIGURE 3

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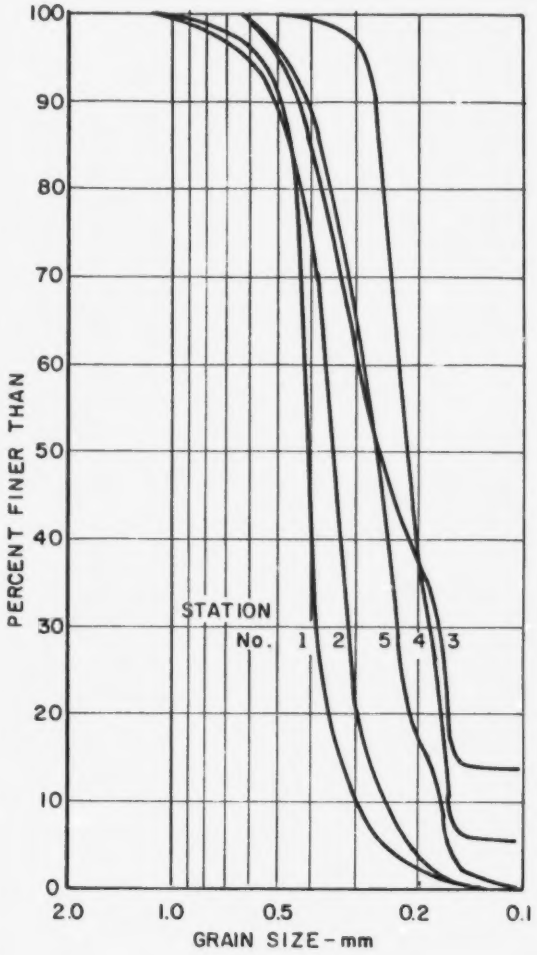
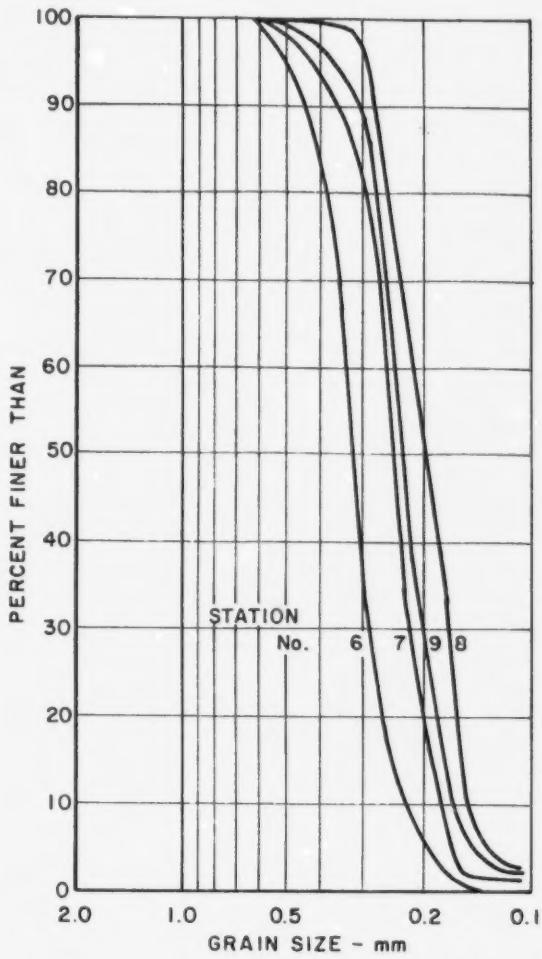
bcil 6638 A-WCH sm 82

STURGEON BANK



COARSE	MEDIUM	FINE
SAND SIZE		

ROBERTS BANK



COARSE	MEDIUM	FINE
SAND SIZE		

FRASER FORESHORE SEDIMENT STUDY

NATIVE SAND GRAIN SIZE DISTRIBUTIONS

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

bcil 6639A-WCH sm 83

FIGURE 5

5A - DEPOSITING DYED SAND AT STATION I

5B - INSTALLATION OF CONTINOUSLY RECORDING ACOUSTIC CURRENT METER

SETTING OUT STATIONS

FIGURE 6

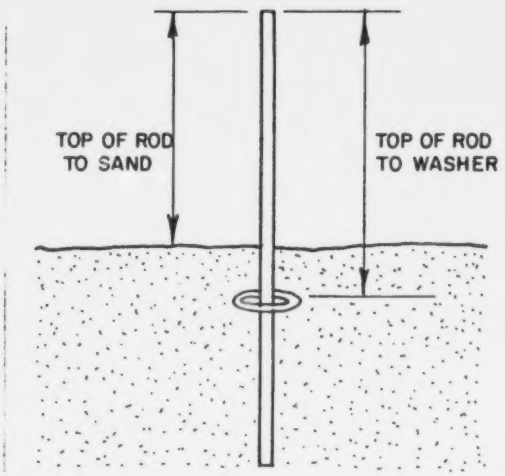
6A - TRACER SAND IN PLACE WITH TIDE COMING IN AT STATION I

6B - DYED SAND AT STATION I AFTER 24 HOURS

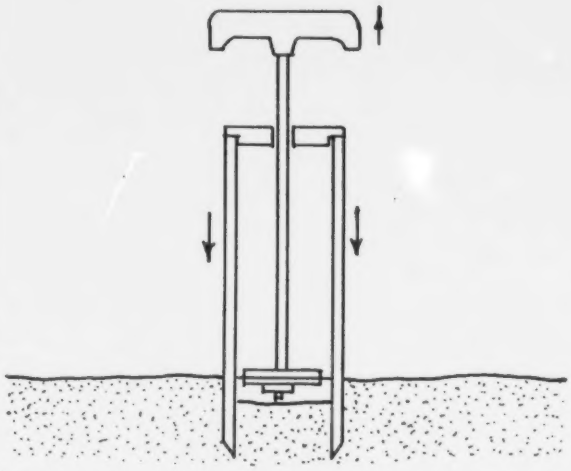
6 - DYED SAND AT STATION I

FIGURE 7

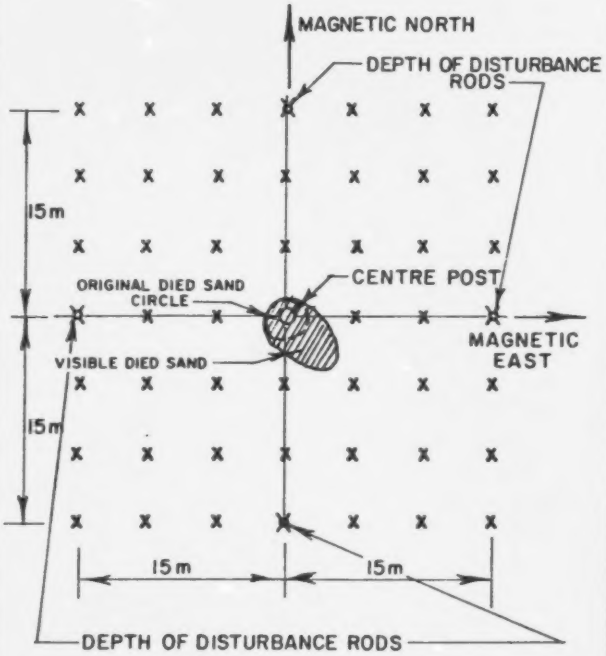
A) DEPTH OF DISTURBANCE ROD



B) SAND SAMPLING CORER

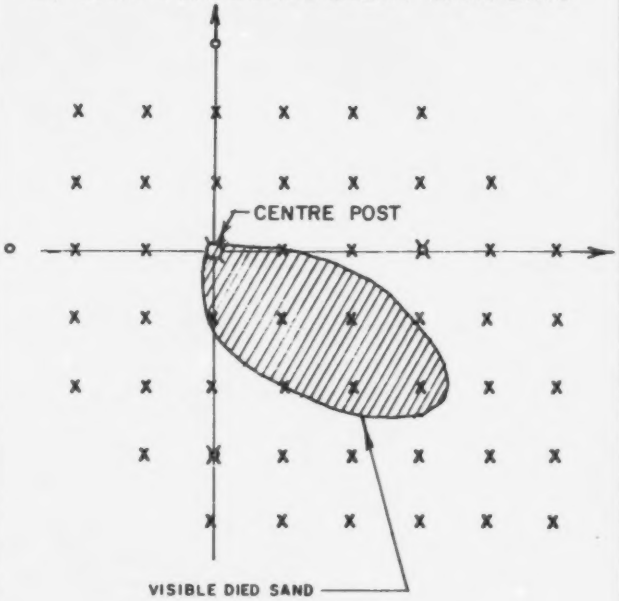


C) GRID FOR FIRST SAMPLING



X'S DENOTE SAMPLING LOCATIONS.

D) GRID FOR SUBSEQUENT SAMPLING



(EXAMPLE) ADJUSTED FOR DIRECTION OF TRACER SAND MOVEMENT

FRASER FORESHORE SEDIMENT STUDY

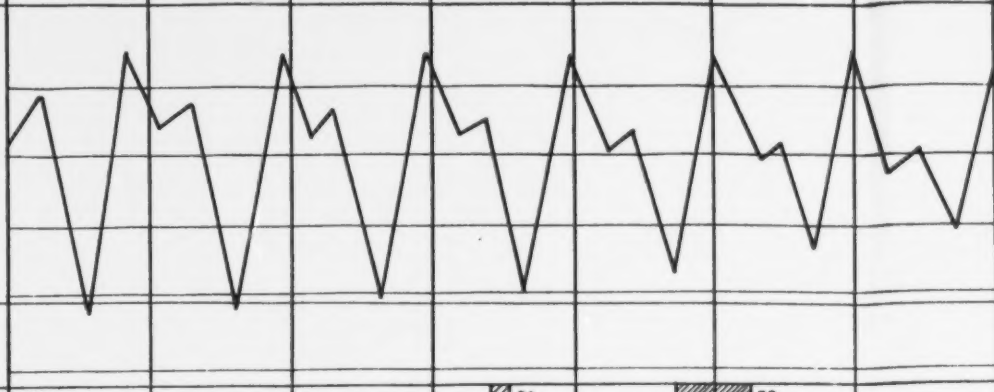
FIELD SAMPLING TECHNIQUE

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

bcil 6639A-WCH

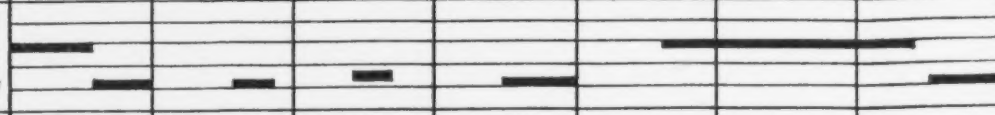
DATE : JUNE	8	9	10	11	12	13	14
STATION ACTIVITY	TRACER SAND PLACEMENT		SAMPLING VISIT				

TIDE HEIGHT (m)



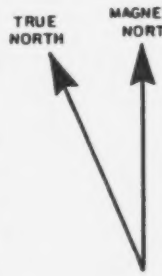
STORMS (Km/hr)	MAX			24		30	
	AVG			20		21	

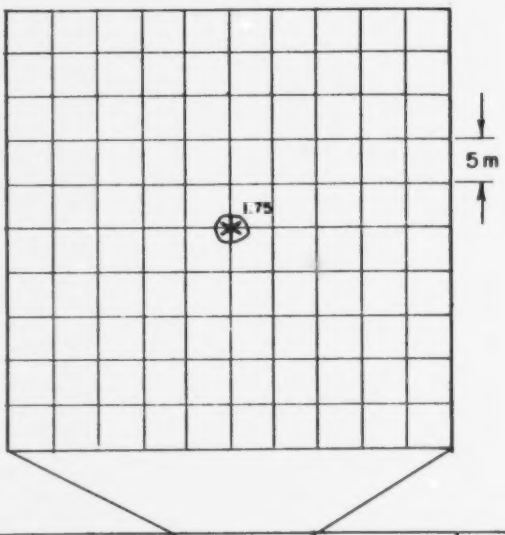
WIND DIRECTION



OBSERVED BED FORMS							
DUNES ORTHOG.	DIRECT.			WSW			
	HEIGHT			50cm			
	LENGTH			100m			
RIPPLES	DIRECT.			TO NNW			
	HEIGHT			2 cm			
	LENGTH			10-15cm			

ISOCONCENTRATION CONTOURS (%)





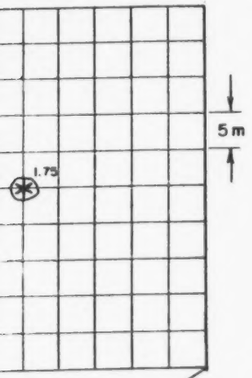
RIVER DISCHARGE (m^3/sec.)	8570	8370	7970	7680	7660	7950	8250

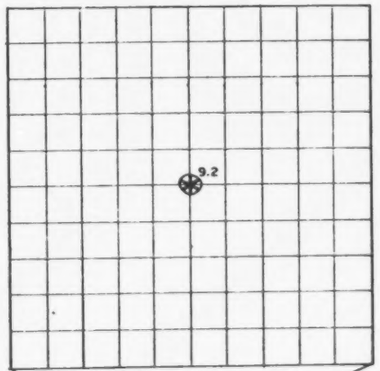
SITE COMMENTS

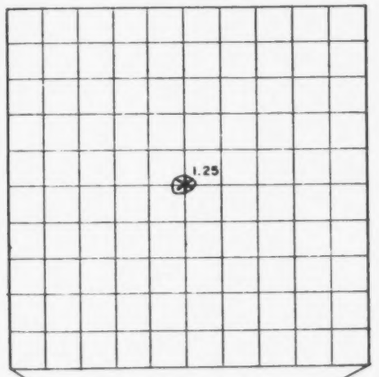
Fine clay
Silt in tro

FIGURE 8

10	11	12	13	14	15	16	17	18	19	20	21	22	23	24		
SAMPLING VISIT									SAMPLING VISIT					SAMPLING VISIT		
	24 / 20		30 / 21					32 / 21	22 / 20							
WSW									WSW					WSW		
50cm									< 50cm					< 10cm		
100m									100m					10m		
TO NNW									TO WNW					TO NW		
2cm									1-3cm					2-3cm		
10-15cm									10cm					10cm		







7970	7680	7660	7950	8250	8650	9150	9590	9790	9830	9730	9670	9690	9690	9670	9700	

Fine clayey silt deposited since last visit.
Silt in troughs of ripples - layers up to 7 cm deep. →

Most of silt
now gone.
Dyed sand appears
buried under sand.

FRASER FORESHORE SEDIMENT STUDY

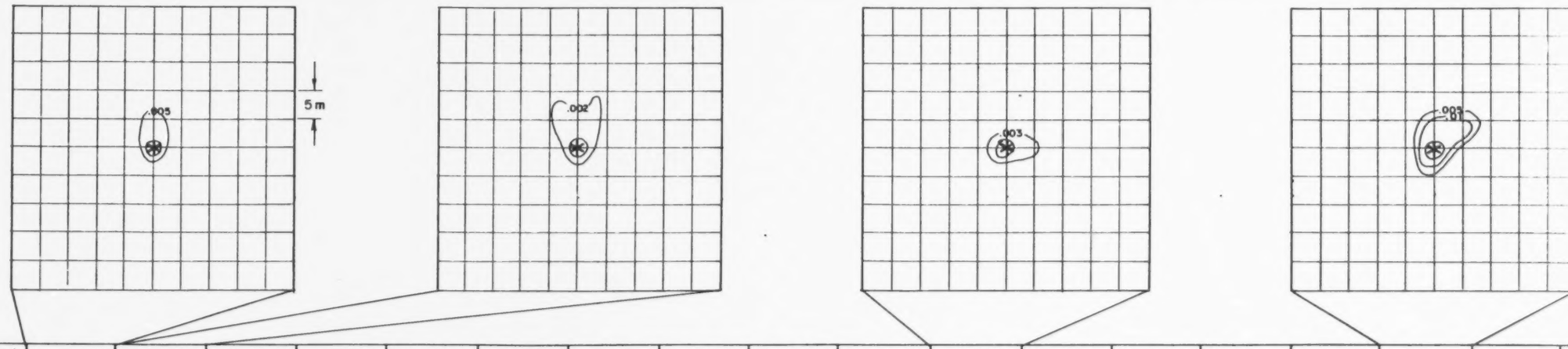
STUDY HISTORY
STATION - 2

DATE : JUNE	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
STATION ACTIVITY	TRACER SAND PLACEMENT	SAMPLING VISIT	SAMPLING VISIT									SAMPLING VISIT					SAMPLING VISIT
TIDE HEIGHT (m) STATION 3 BED LEVEL																	
STORMS (Km/hr)	MAX AVG			24 20		30 21				32 21	22 20						
WIND DIRECTION N E S W																	
OBSERVED BED FORMS — DUNES ORTHOG. — DIRECT.	WNW	WNW	WNW									W					WNW
DUNES ORTHOG. — HEIGHT	2 – 3 cm	3 – 4 cm	5 cm									10 cm					3 cm
DUNES ORTHOG. — LENGTH	2 m	2 m	2 m									10 m					20 m
RIPPLES — DIRECT.	TO ENE	TO ENE	TO ENE									TO WSW					TO WSW
RIPPLES — HEIGHT	1 cm	1 cm	1 – 2 cm									2 cm					2 cm
RIPPLES — LENGTH		15 cm	10 cm									10 cm					14 cm

ISOCONCENTRATION CONTOURS (%)

TRUE NORTH

MAGNETIC NORTH



RIVER DISCHARGE (m^3/sec.)	8570	8370	7970	7680	7660	7950	8250	8650	9150	9590	9790	9830	9730	9670	9690	9690	9670	9700

SITE COMMENTS

Tide ebbs very quickly.

Sand does not appear to have migrated appreciably.

Lots of dyed sand visible at original placement area.
Dyed sand visible at 1.25 m from original spot, to the NNE.
Free dye clearly visible over study area.

Free dye still visible.
Dyed sand visible.

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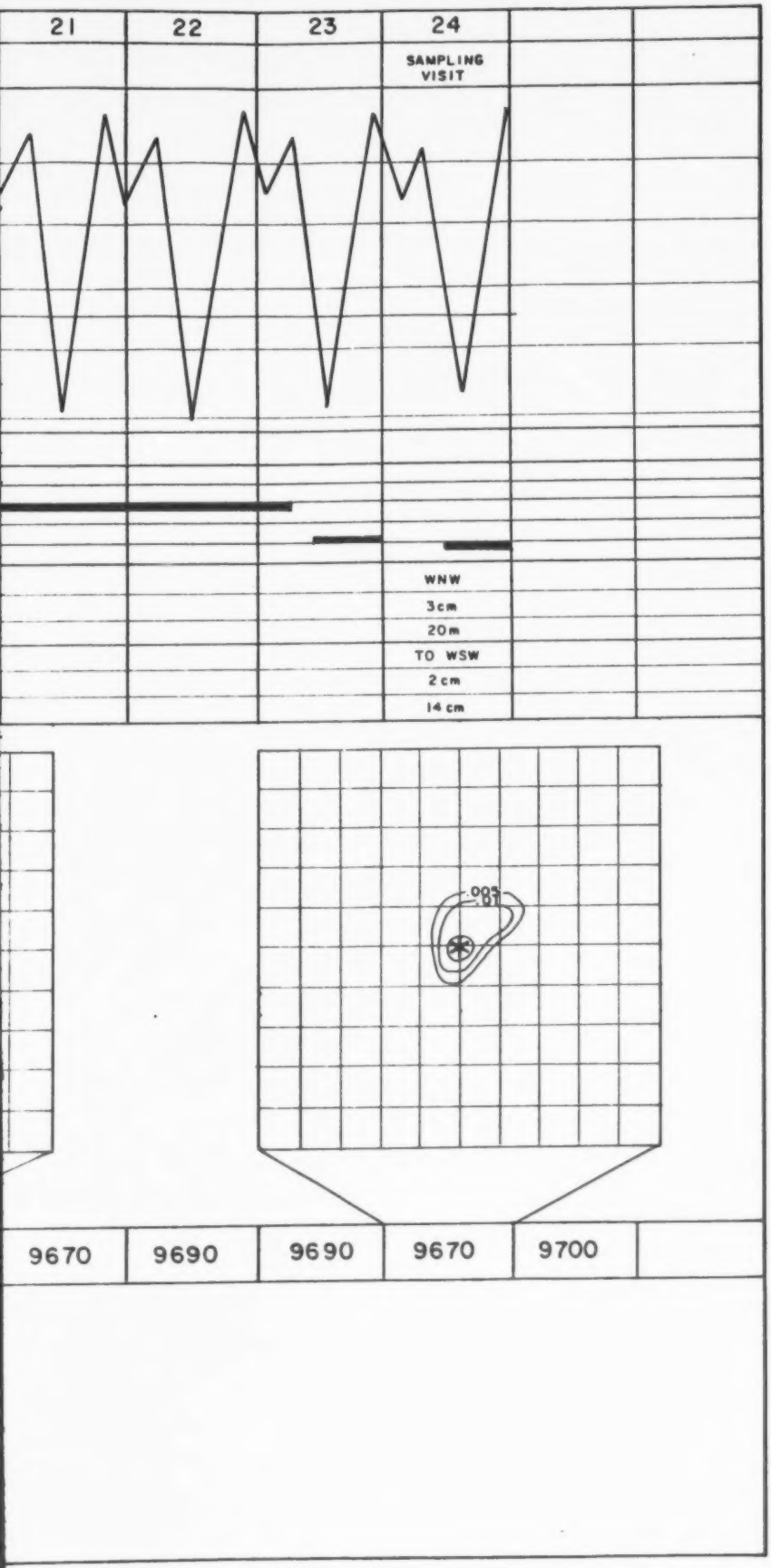
FIGURE 9



FRASER FORESHORE SEDIMENT STUDY

STUDY HISTORY
STATION - 3

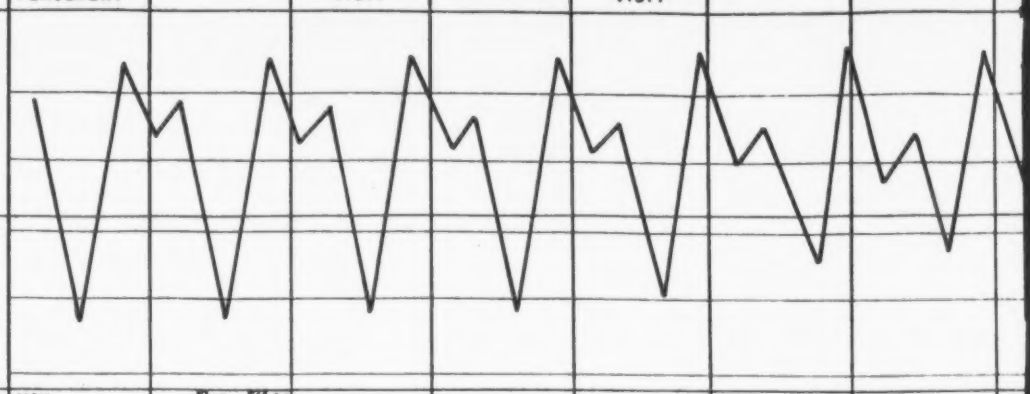
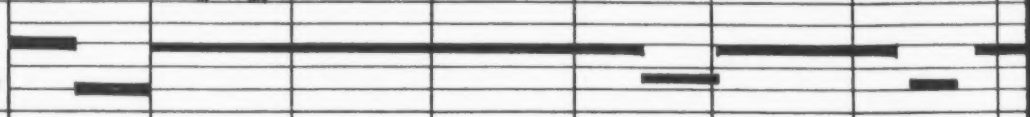
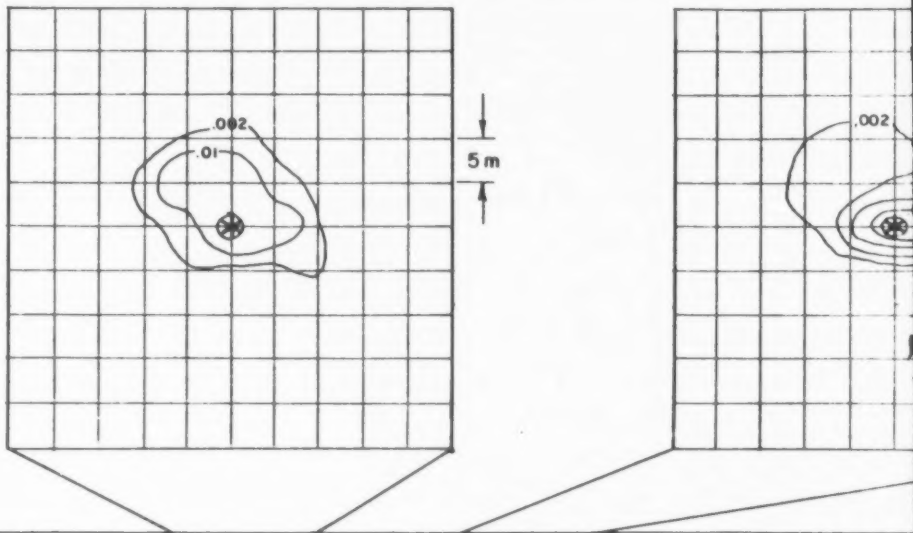
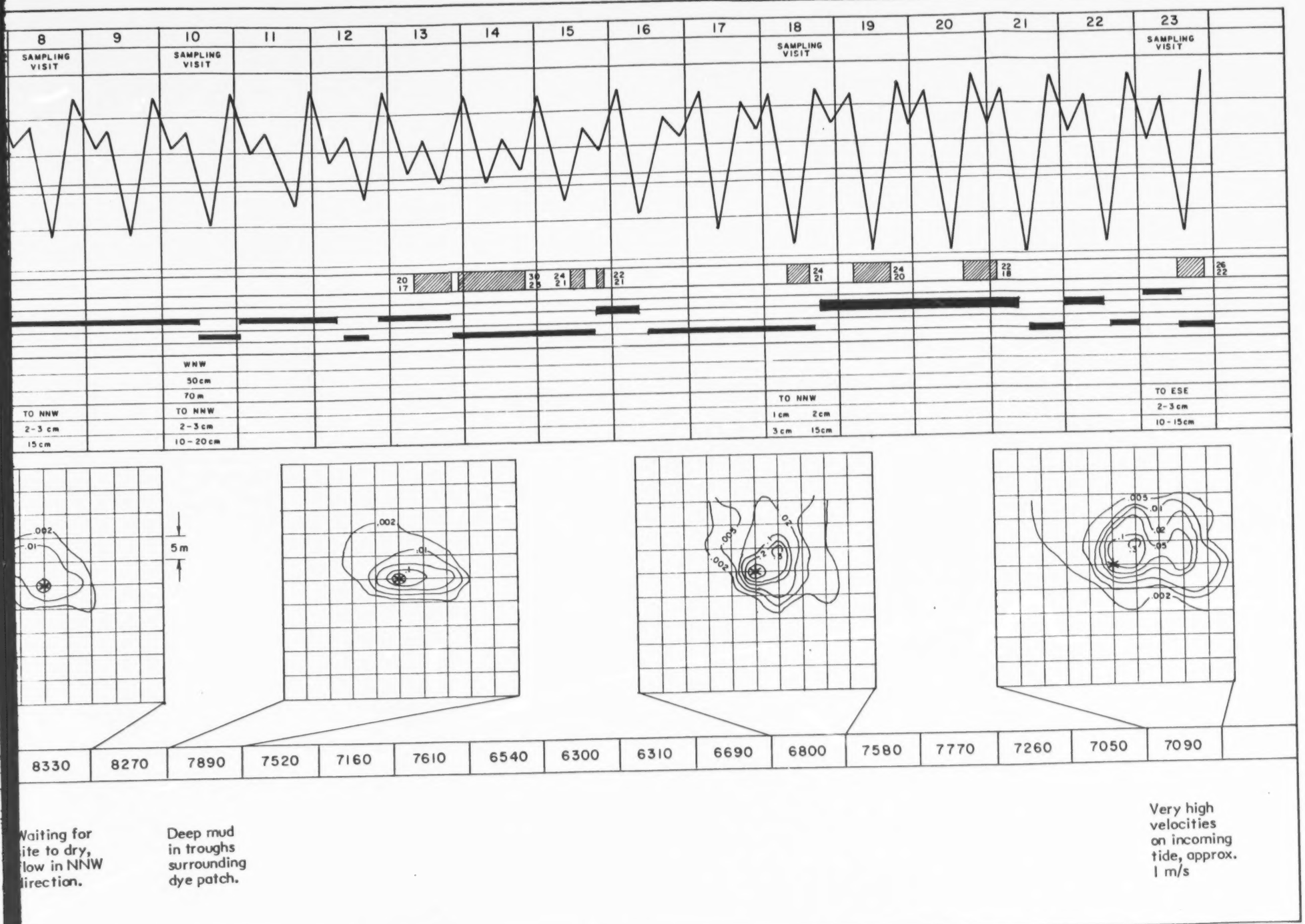
DATE : JULY	6	7	8	9	10	11	12	
STATION ACTIVITY	TRACER SAND PLACEMENT		SAMPLING VISIT		SAMPLING VISIT			
TIDE HEIGHT (m) STATION 4 BED LEV.								
STORMS (Km/hr)	MAX AVG	19 19	24 21					
WIND DIRECTION N E S W								
OBSERVED BED FORMS — DUNES ORTHOG. — DIRECT.	NW				WNW			
DUNES ORTHOG. — HEIGHT	60-70 cm				50 cm			
DUNES ORTHOG. — LENGTH					70 m			
RIPPLES — DIRECT.	TO NW		TO NNW		TO NNW			
RIPPLES — HEIGHT	2 cm		2-3 cm		2-3 cm			
RIPPLES — LENGTH	10-15 cm		15 cm		10-20 cm			
ISOCONCENTRATION CONTOURS (%)								
RIVER DISCHARGE (m^3/sec.)	7950	8110	8330	8270	7890	7520	7160	
SITE COMMENTS			Waiting for site to dry, flow in NNW direction.		Deep mud in troughs surrounding dye patch.			

FIGURE 10

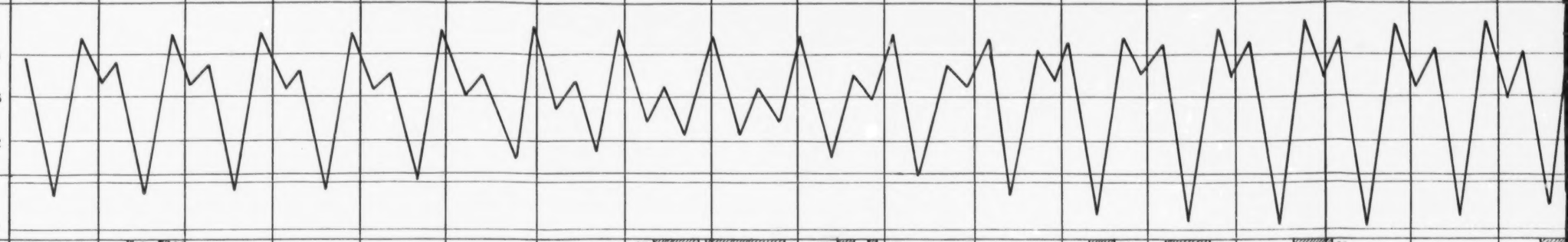


FRASER FORESHORE SEDIMENT STUDY

STUDY HISTORY
STATION - 4

DATE : JULY	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
STATION ACTIVITY	TRACER SAND PLACEMENT		SAMPLING VISIT		SAMPLING VISIT													SAMPLING VISIT

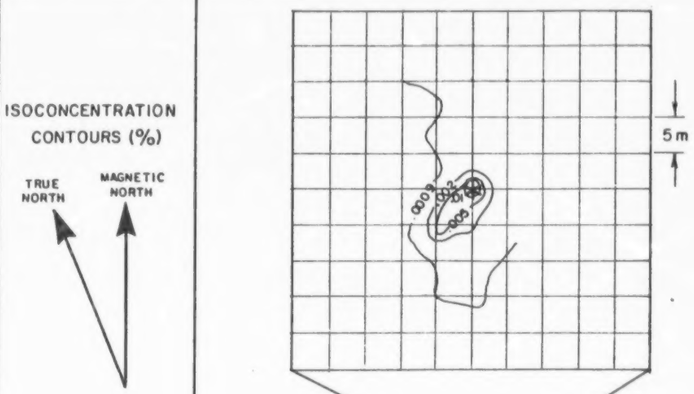
TIDE HEIGHT (m) — STATION 5 BED LEVEL 1



STORMS (Km/hr)	MAX AVG	19 19	24 21						20 17	30 25	24 21	22 21			24 21	24 20	22 18	
WIND DIRECTION	N E S W																	
OBSERVED BED FORMS — DUNES ORTHOG. — DIRECT.	WNW		WNW															
DUNES ORTHOG. — HEIGHT	50 cm		50cm															
DUNES ORTHOG. — LENGTH	50 m		70 m															
RIPPLES — DIRECT.	TO WNW		TO WNW		TO WNW													TO WNW
RIPPLES — HEIGHT	1-2 cm		1-2 cm		1-2 cm													2-3 cm
RIPPLES — LENGTH	8 cm		6-9 cm		10-15 cm													15 cm

ISOCONCENTRATION CONTOURS (%)

TRUE NORTH / MAGNETIC NORTH



RIVER DISCHARGE (m^3/sec.)	7950	8110	8330	8270	7890	7520	7160	7610	6540	6300	6310	6690	6800	7580	7770	7260	7050	7090

SITE COMMENTS

Dye patch relatively undisturbed - very little movement. Small amount of sand deposited on dye patch.

Dye patch quite undisturbed - small amount of silt deposited in ripples.

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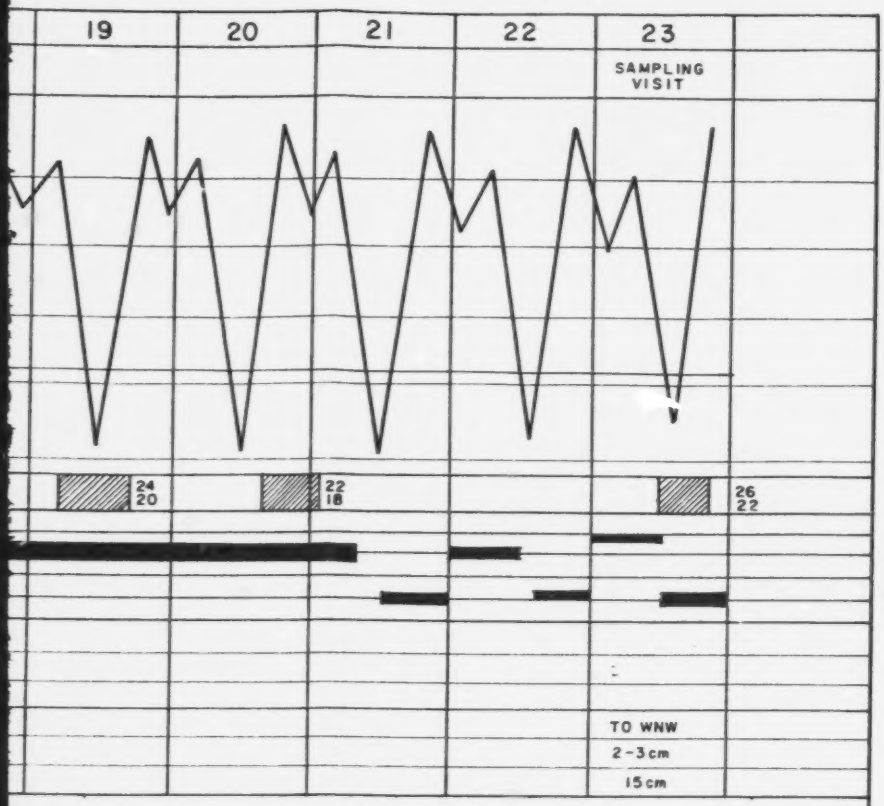
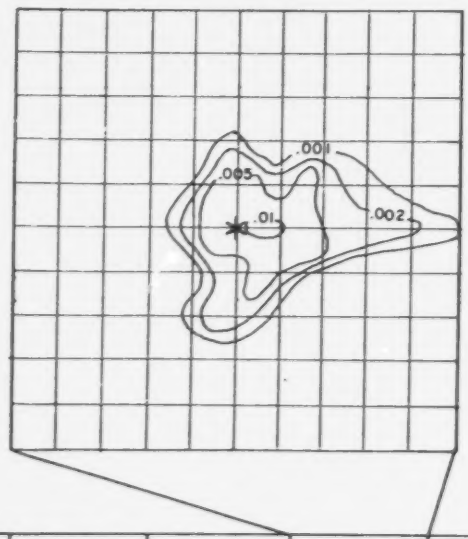
FIGURE 11

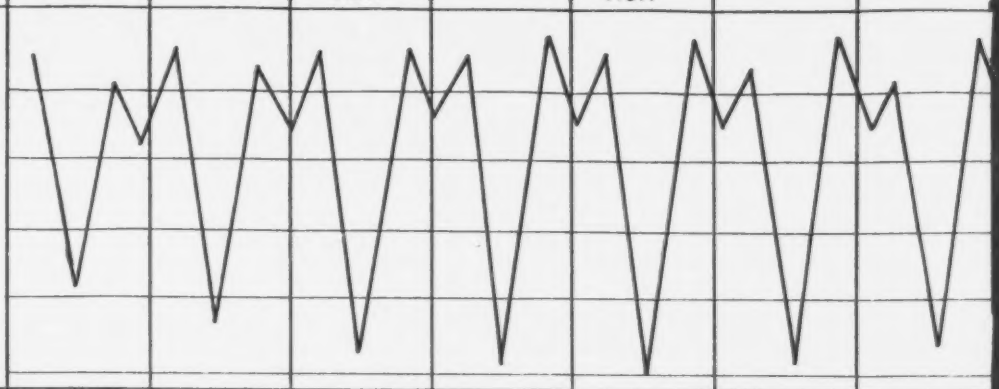
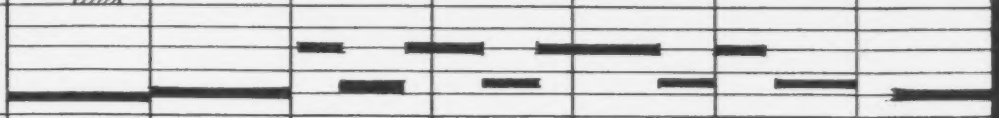
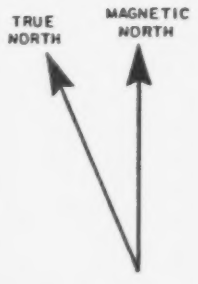
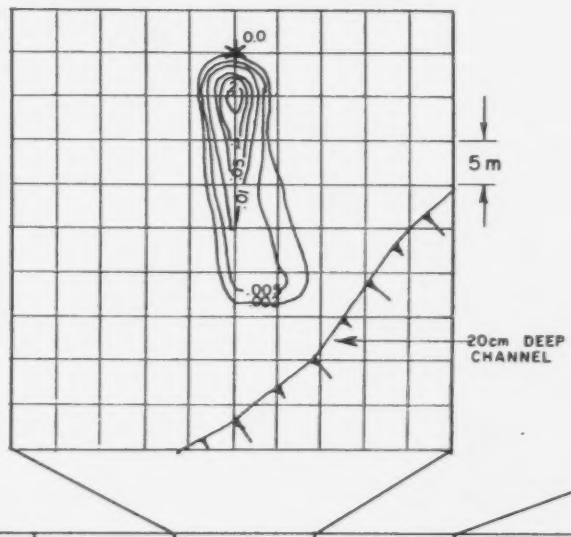




7580	7770	7260	7050	7090	

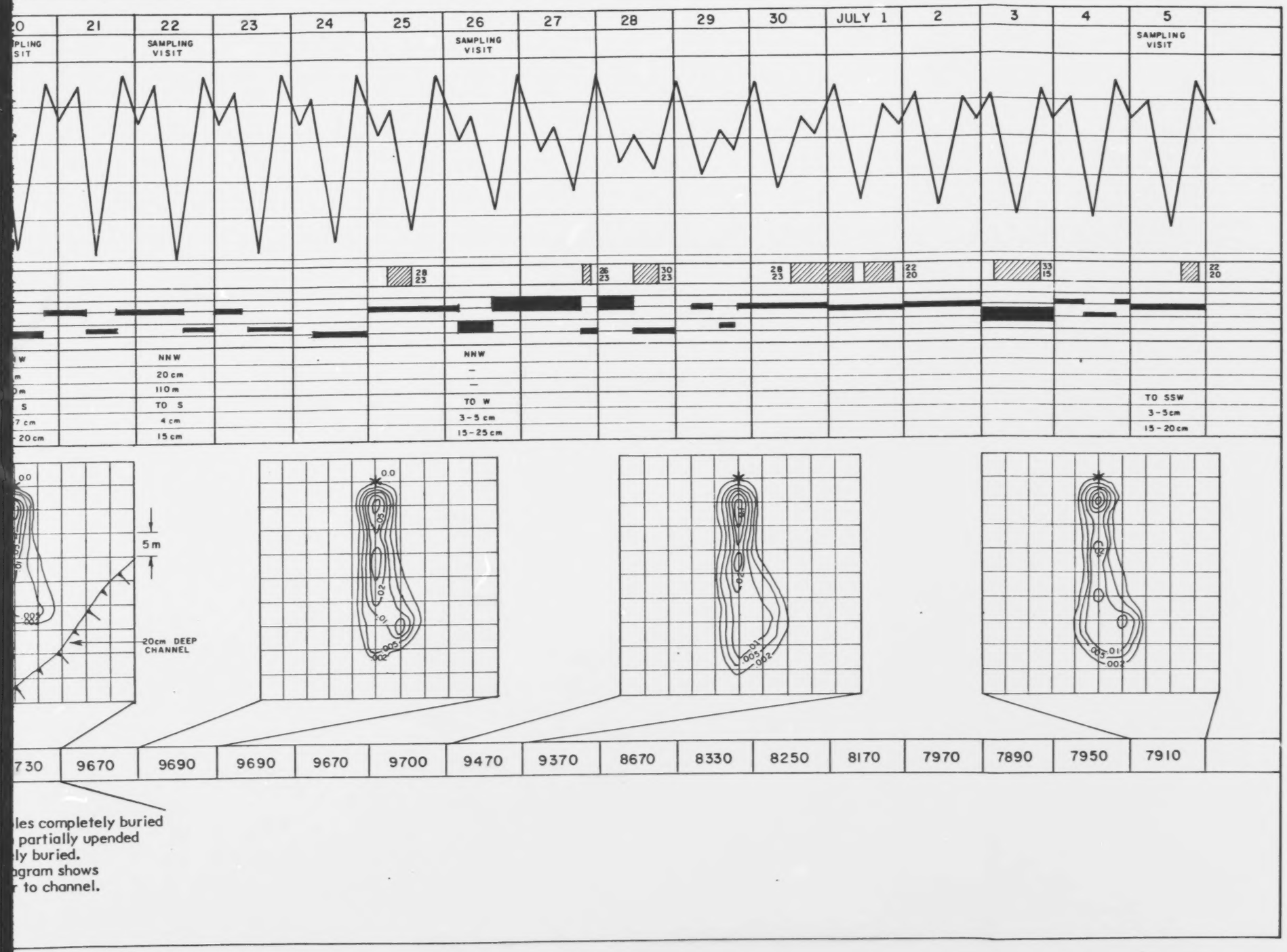
FRASER FORESHORE SEDIMENT STUDY

STUDY HISTORY
STATION - 5

DATE : JUNE			18	19	20	21	22	23	24
STATION ACTIVITY			TRACER SAND PLACEMENT		SAMPLING VISIT		SAMPLING VISIT		
TIDE HEIGHT (m) STATION 6 BED LEVEL									
STORMS (Km/hr)			MAX 22 AVG 20						
WIND DIRECTION									
OBSERVED BED FORMS	DUNES ORTHOG.	DIRECT.			NNW		NNW		
		HEIGHT			1 m		20 cm		
		LENGTH			100 m		110 m		
	RIPPLES	DIRECT.	TO SSE		TO S		TO S		
		HEIGHT	5 - 10 cm		5 - 7 cm		4 cm		
		LENGTH	15 - 30 cm		10 - 20 cm		15 cm		
ISOCONCENTRATION CONTOURS (%)									
RIVER DISCHARGE (m^3/sec.)			9790	9830	9730	9670	9690	9690	9670
SITE COMMENTS			Control samples completely buried Sediment pan partially upended and completely buried. Field note diagram shows isopleths near to channel.						

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

FIGURE 12



les completely buried
partially upended
ly buried.
gram shows
r to channel.

FRASER FORESHORE SEDIMENT STUDY

STUDY HISTORY
STATION - 6

DATE : JUNE	18	19	20	21	22	23	24	25	26	27	28	29	30	JULY 1	2	3	4	5
STATION ACTIVITY	TRACER SAND PLACEMENT			SAMPLING VISIT	SAMPLING VISIT				SAMPLING VISIT									SAMPL VISIT

TIDE HEIGHT (m) — STATION 7 BED LEVEL — 0, 1, 2, 3, 4

STORMS (Km/hr) — MAX AVG: 22 20; 28 23; 26 23; 30 23; 28 23; 22 20; 33 15

WIND DIRECTION — N E S W

OBSERVED BED FORMS			18	21	22	25	26	28	30	JULY 1	3	5
	DUNES ORTHOG.	DIRECT.	WSW	WSW	N		NNW					N
		HEIGHT	10 cm	10 cm	10 cm		10 cm					10 cm
		LENGTH	10 m	4 - 5 m	10 m		10 m					10 m
	RIPPLES	DIRECT.	TO ENE	TO W	TO WSW		TO WSW					TO SSW
		HEIGHT	2 - 3 cm	2 - 3 cm	2 - 5 cm		2 - 4 cm					2 - 3 cm
		LENGTH	15 cm	15 - 20 cm	10 - 20 cm		15 - 20 cm					10 - 20

ISOCONCENTRATION CONTOURS (%)

TRUE NORTH / MAGNETIC NORTH

5 m

RIVER DISCHARGE (m^3/sec.)	9790	9830	9730	9670	9690	9690	9670	9700	9470	9370	8670	8330	8250	8170	7970	7890	7950	7910

SITE COMMENTS

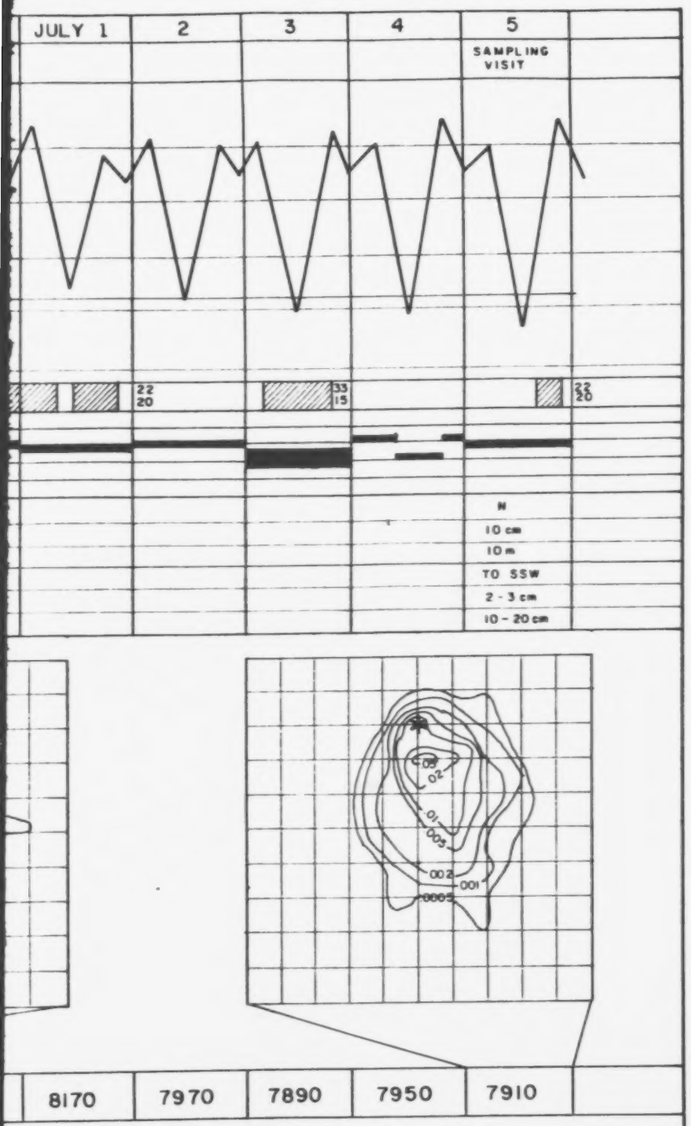
Original placement area covered over or moved. Tracer sand visible up to 15 m SW. Core at (0,0) showed small 2 cm^3 volume of tracer sand at 2 cm depth. Two other cores showed no tracer.

Sediment pan had sand in all four compartments. Appeared equal amounts.

Some po of claye present.

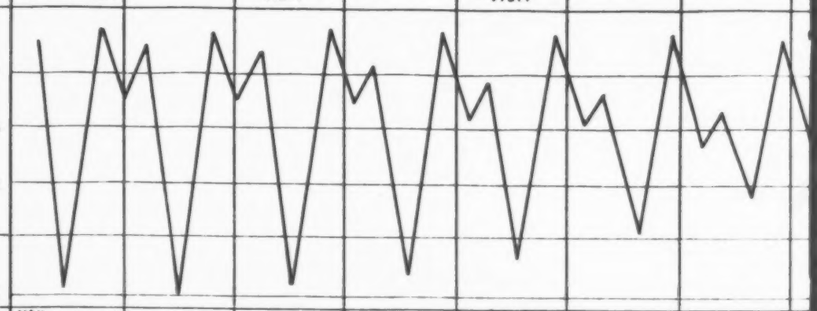
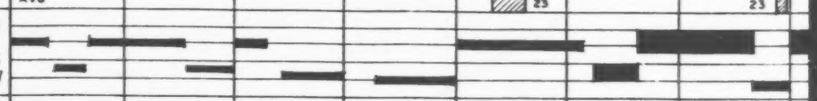
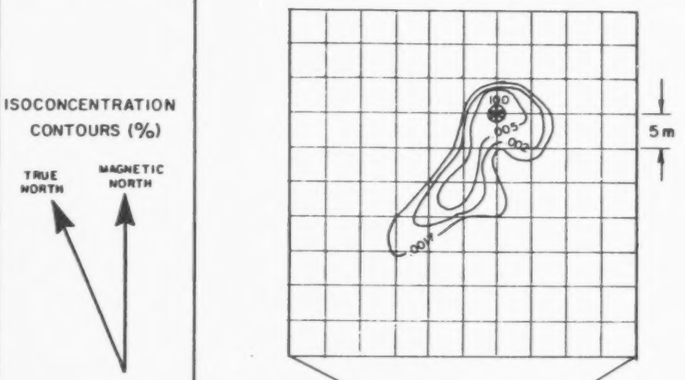
WESTERN CANADA HYDRAULIC LABORATORIES LTD.

FIGURE 13



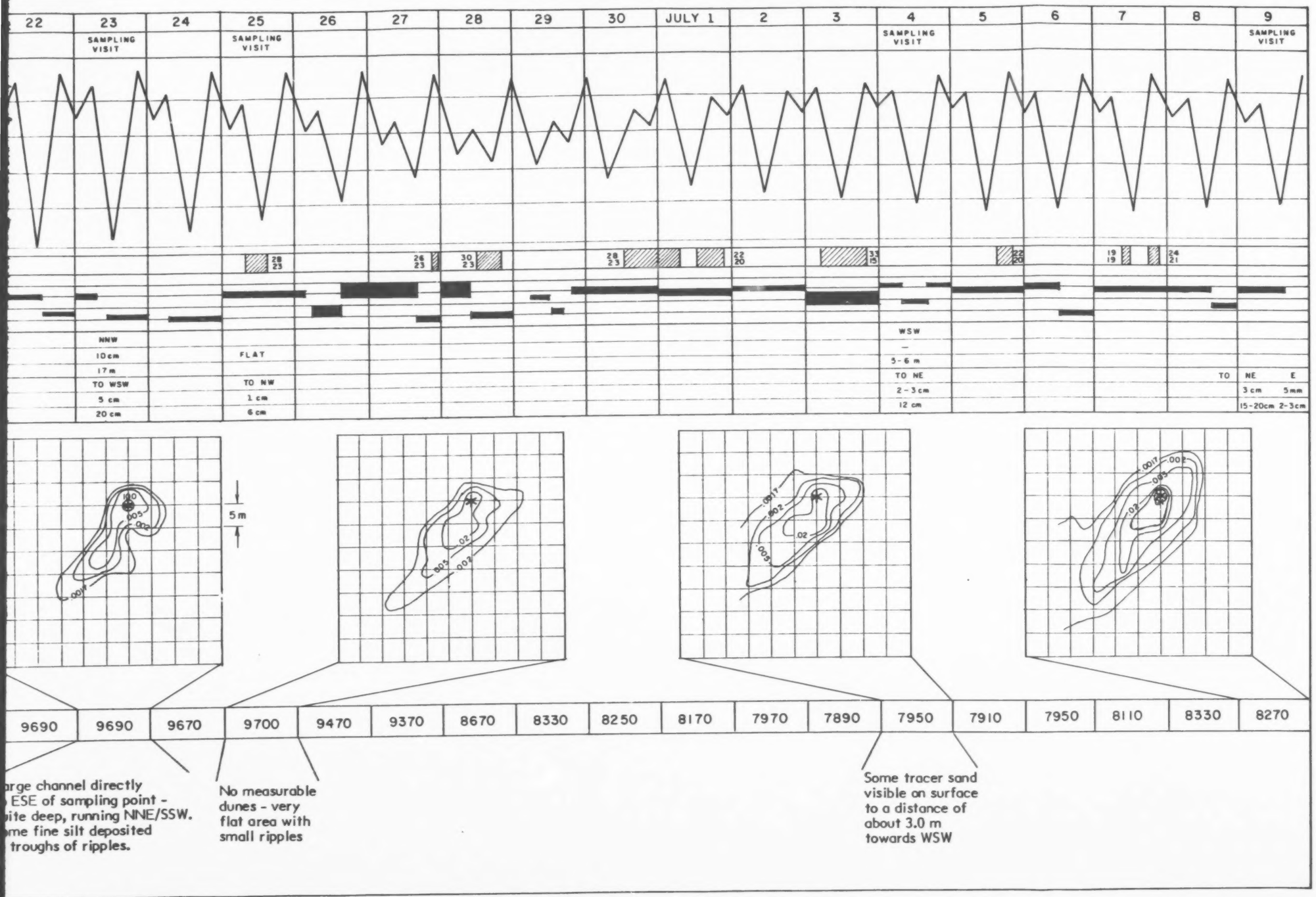
FRASER FORESHORE SEDIMENT STUDY

STUDY HISTORY
STATION - 7

DATE : JUNE			21	22	23	24	25	26	27
STATION ACTIVITY			TRACER SAND PLACEMENT		SAMPLING VISIT		SAMPLING VISIT		
TIDE HEIGHT (m)									
STORMS (Km/hr)			MAX AVG				28 23		26 23
WIND DIRECTION									
OBSERVED BED FORMS	DUNES ORTHOG.	DIRECT.	NNW		NNW				
		HEIGHT	20 cm		10 cm		FLAT		
		LENGTH	10 m		17 m				
	RIPPLES	DIRECT.	TO WSW		TO WSW		TO NW		
		HEIGHT	2 - 5 cm		5 cm		1 cm		
		LENGTH	10 - 20 cm		20 cm		6 cm		
ISOCONCENTRATION CONTOURS (%)									
RIVER DISCHARGE (m^3/sec.)			9670	9690	9690	9670	9700	9470	9370
SITE COMMENTS			Large channel directly to ESE of sampling point - quite deep, running NNE/SSW. Some fine silt deposited in troughs of ripples.				No measurable dunes - very flat area with small ripples		

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

FIGURE 14

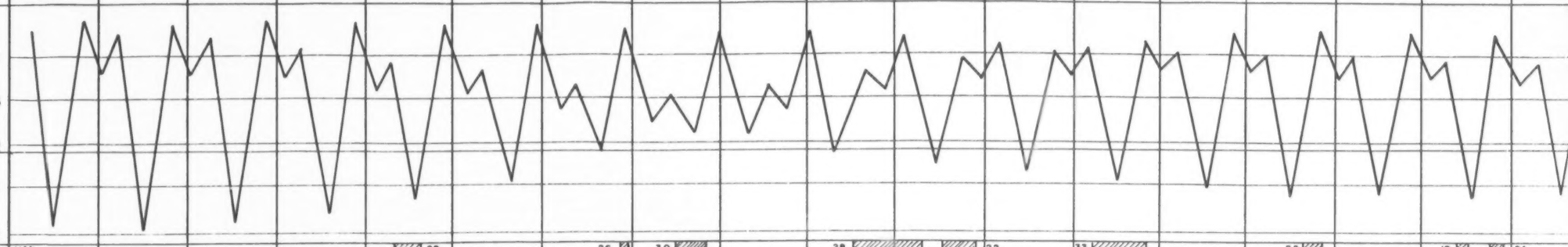


FRASER FORESHORE SEDIMENT STUDY

STUDY HISTORY
STATION - 8

DATE : JUNE	21	22	23	24	25	26	27	28	29	30	JULY 1	2	3	4	5	6	7	8
STATION ACTIVITY	TRACER SAND PLACEMENT		SAMPLING VISIT		SAMPLING VISIT									SAMPLING VISIT				

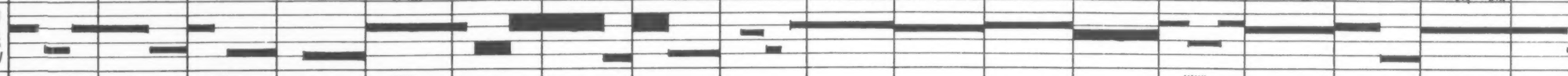
TIDE HEIGHT (m) STATION 9 BED LEVEL



STORMS (Km/hr) MAX AVG

21	22	23	24	25	26	27	28	29	30	JULY 1	2	3	4	5	6	7	8
				28 23		26 23	30 23		28 23		22 20	33 15		22 20		19 19	24 21

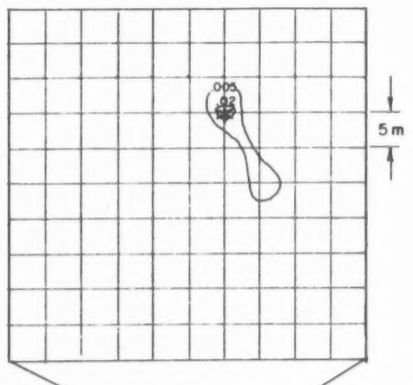
WIND DIRECTION N E S W

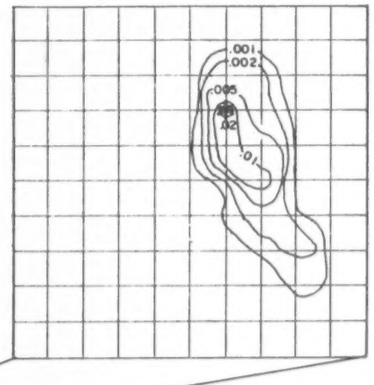


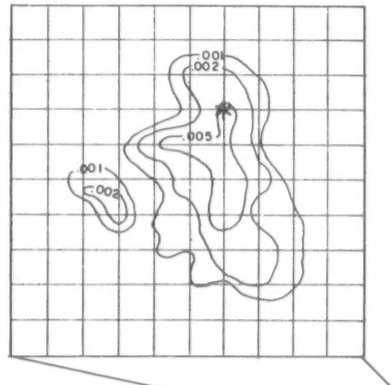
OBSERVED BED FORMS			21	22	23	24	25	26	27	28	29	30	JULY 1	2	3	4	5	6	7	8
	DUNES ORTHOG.	DIRECT.	NW		NNW		NNW									NNW				
		HEIGHT	20cm		20cm		10cm									20-30cm				
		LENGTH	10m		10m		10m									10m				
	RIPPLES	DIRECT.	TO S		TO S		TO S									TO S				
		HEIGHT	2-4cm		3-4cm		2-3cm									2-3cm				
		LENGTH	10-20cm		10cm		10-15cm													

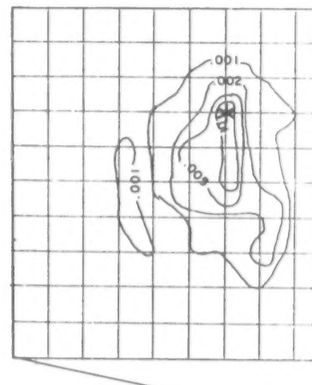
ISOCONCENTRATION CONTOURS (%)

TRUE NORTH MAGNETIC NORTH









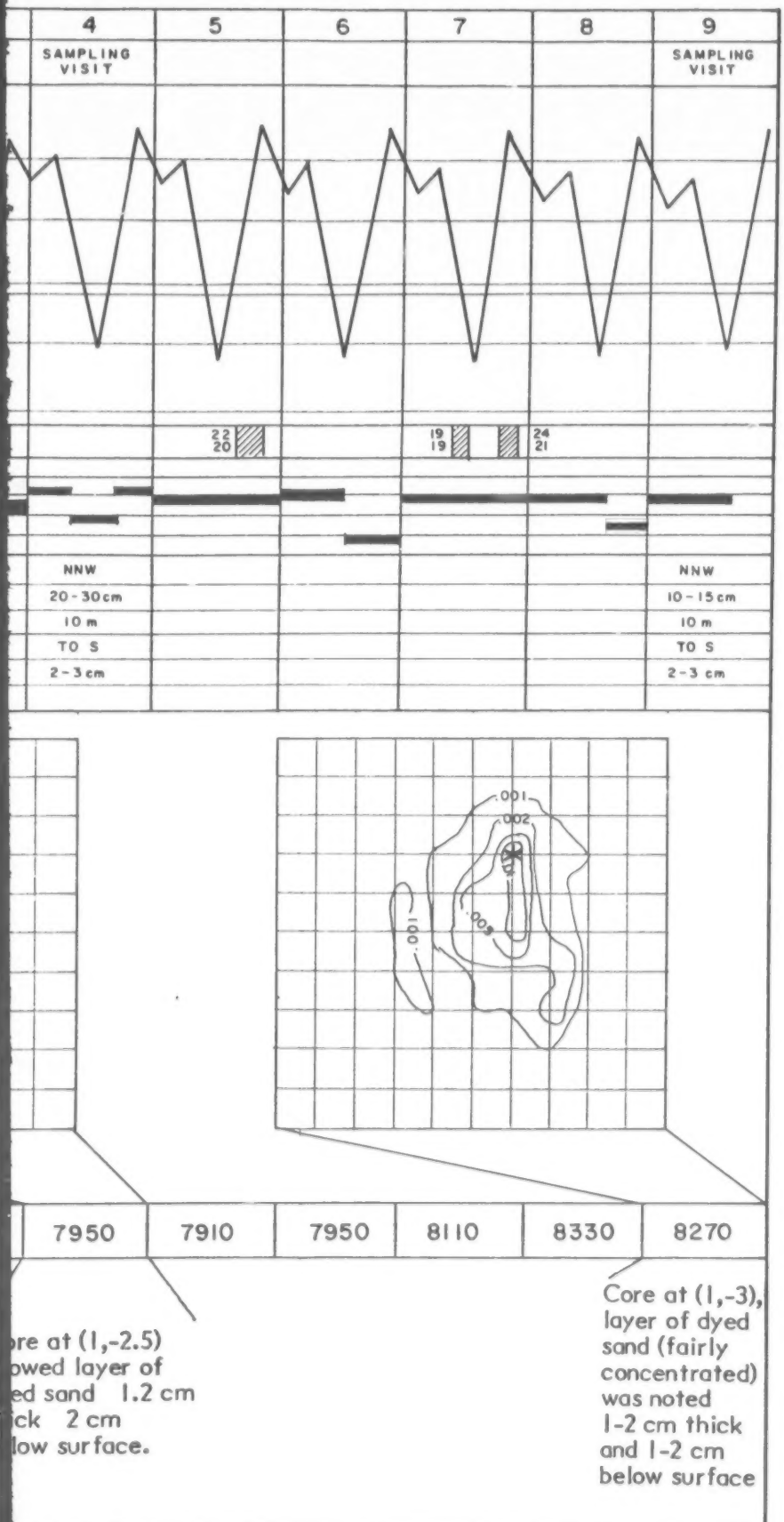
RIVER DISCHARGE (m^3/sec.)	9670	9690	9690	9670	9700	9470	9370	8670	8330	8250	8170	7970	7890	7950	7910	7950	8110	8330

SITE COMMENTS

- Large channel about 100 m SE of station. Looks deep and fairly swiftly flowing. No silt deposits
- Well established drainage streams observed carrying quite large amounts of bedload towards main channel
- Ebb flow in channel measured at 1 m/s.
- Waves 0.5-0.7 m, whitecaps
- Core at (1,-2.5) showed layer of dyed sand 1.2 cm thick 2 cm below surface.

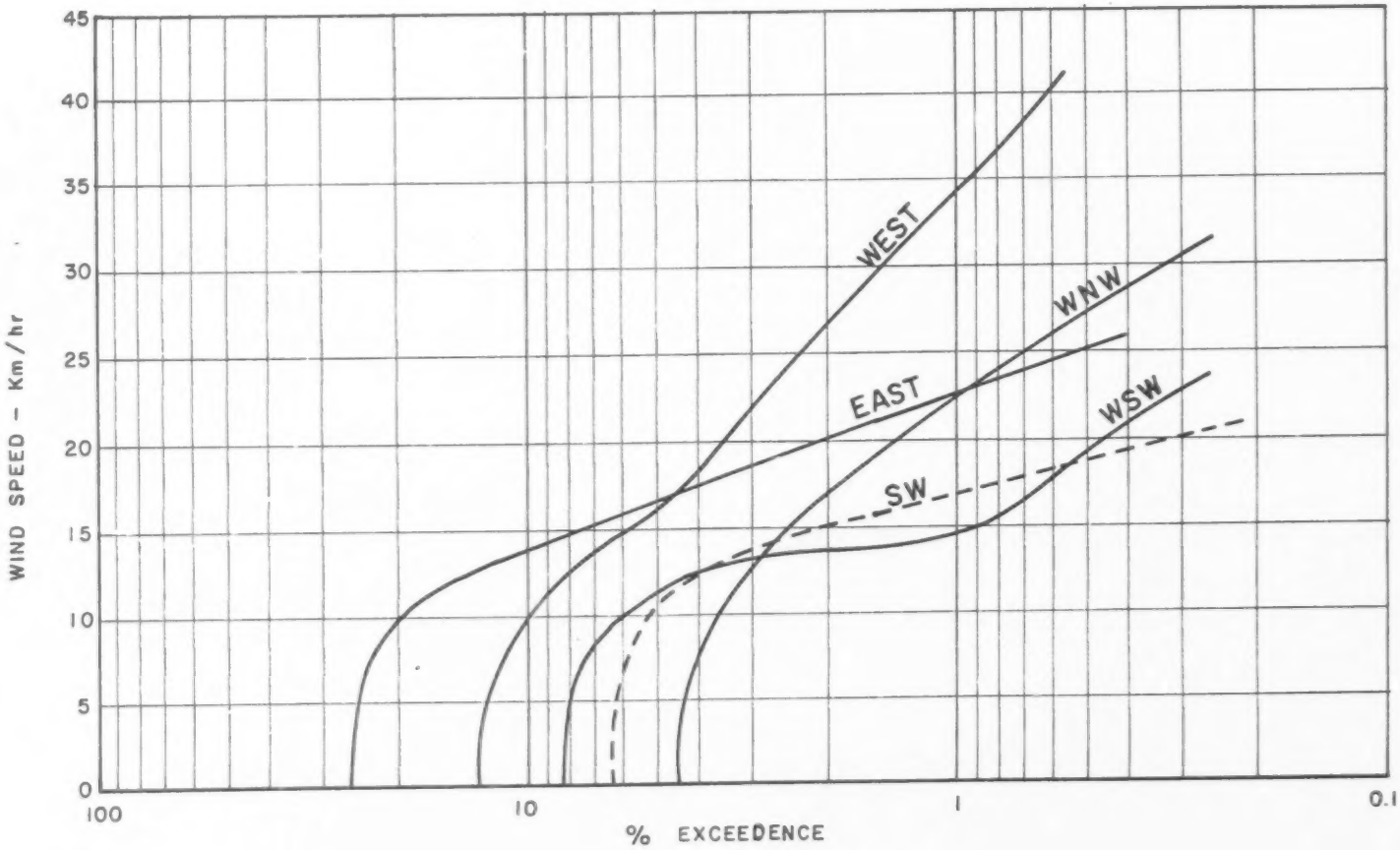
WESTERN CANADA HYDRAULIC LABORATORIES LTD.

FIGURE 15



FRASER FORESHORE SEDIMENT STUDY

STUDY HISTORY
STATION - 9



FRASER FORESHORE SEDIMENT STUDY

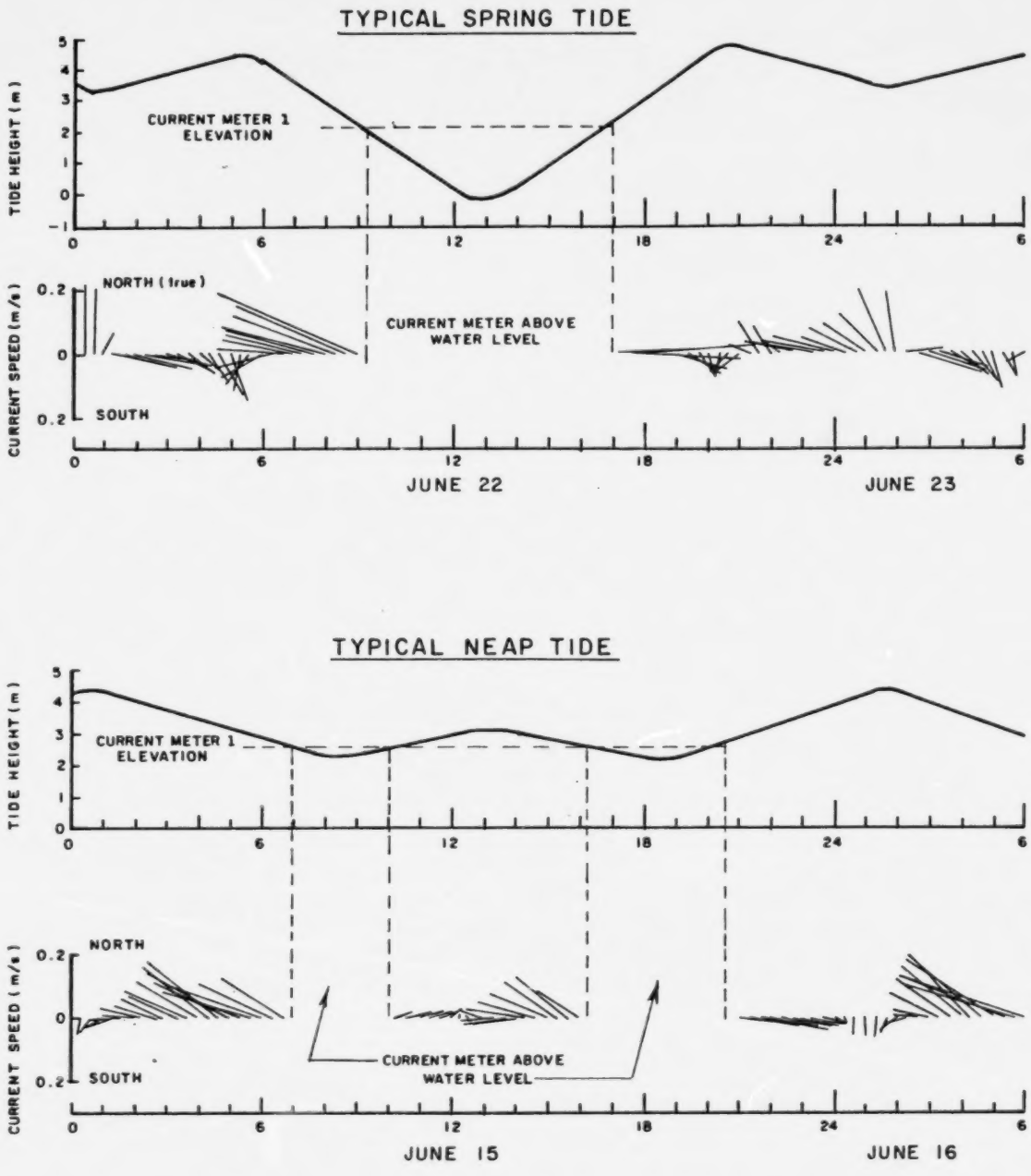
WIND SPEED AND DIRECTION
PERCENTAGE EXCEEDENCE CURVES

FIGURE 16

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

bc11 6638 A-WCH sm 83

FIGURE 17



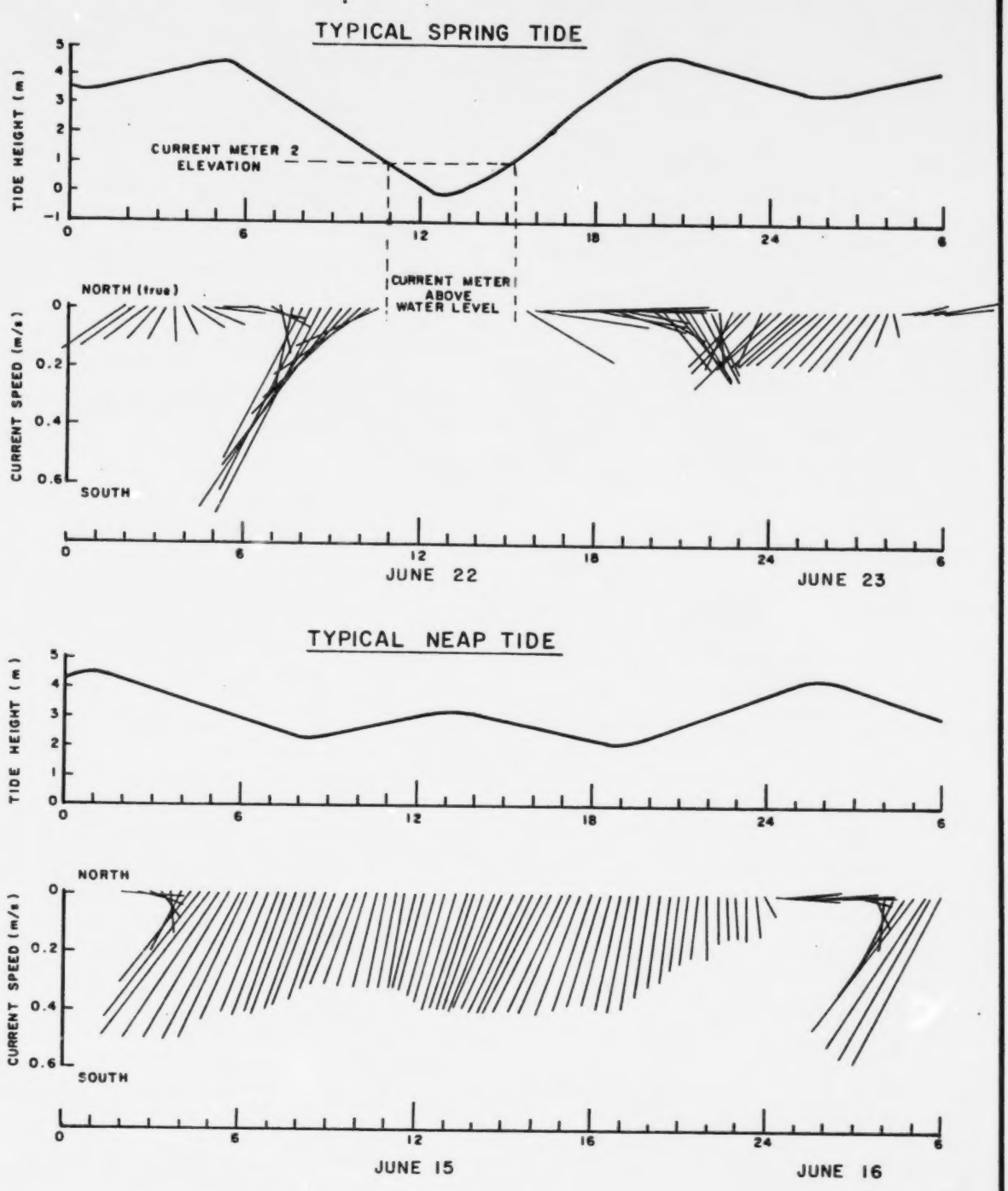
FRASER FORESHORE SEDIMENT STUDY

TYPICAL CURRENT VELOCITIES AT STATION CM 1

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

bcil 6639A-WCH:sm83

FIGURE 18

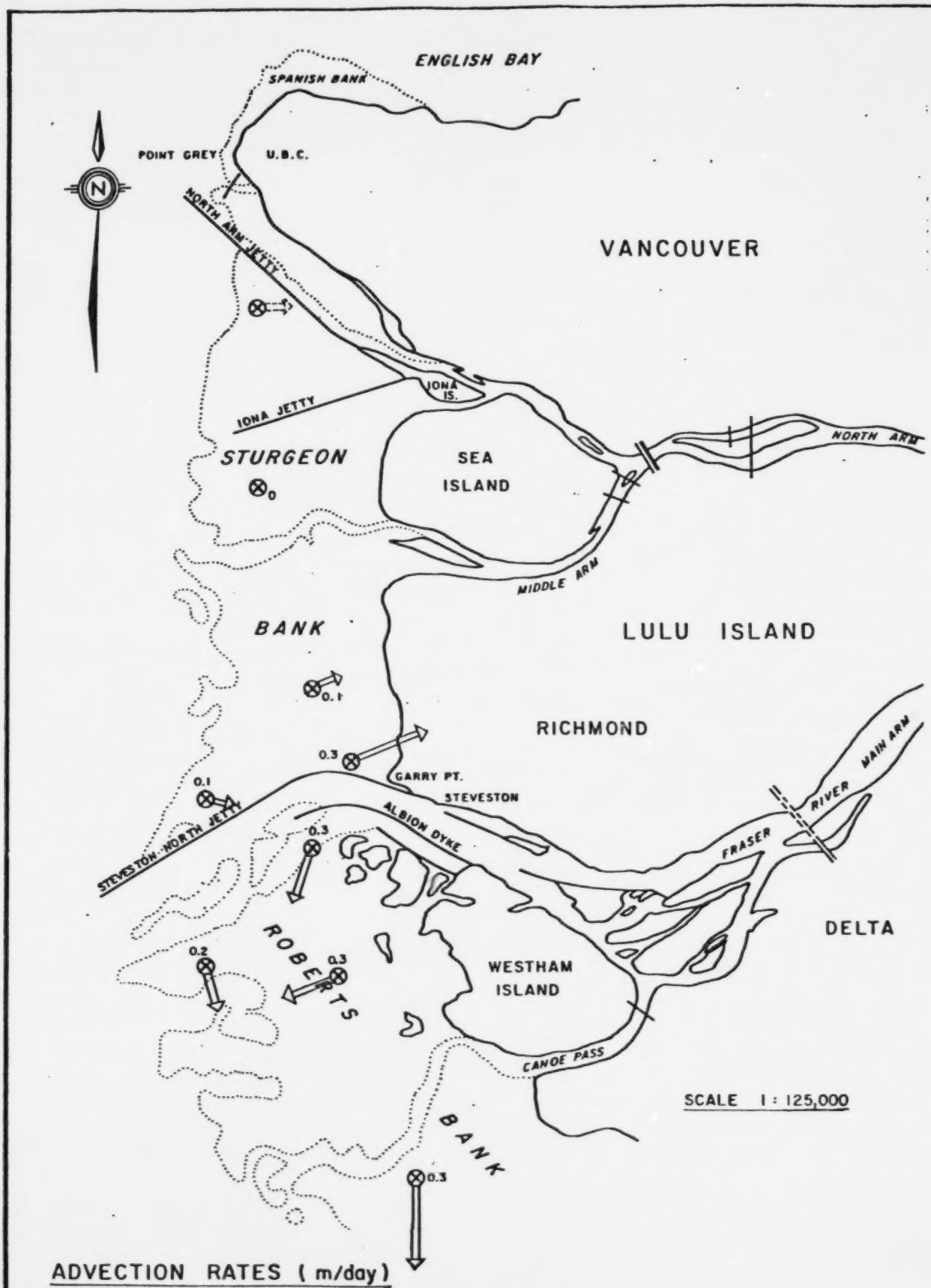


FRASER FORESHORE SEDIMENT STUDY

TYPICAL CURRENT VELOCITIES AT STATION CM 2

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

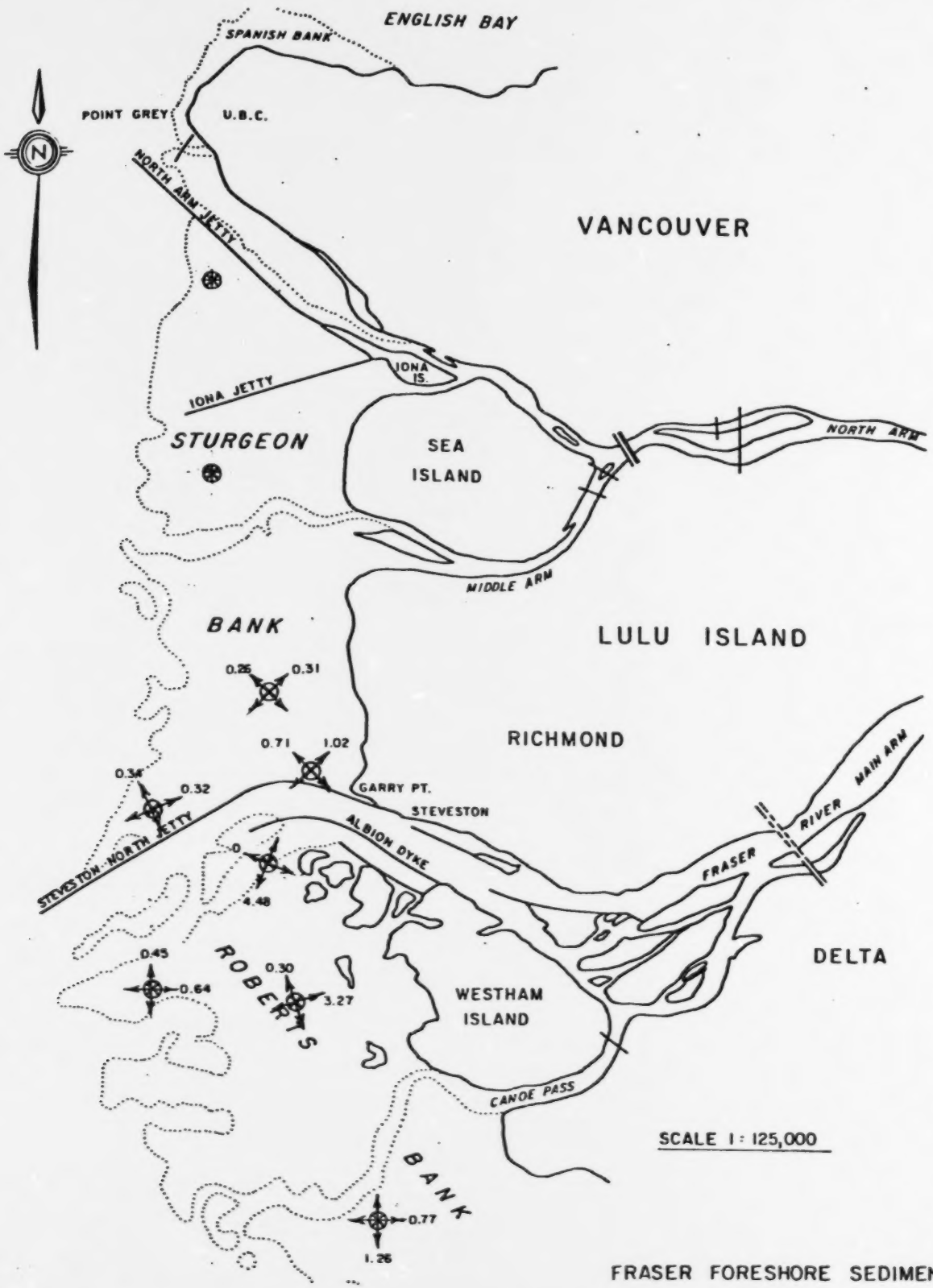
bcil 6639A-WCH sm83



WESTERN CANADA HYDRAULIC LABORATORIES LTD.

bcil6640b-WCH

FIGURE 19

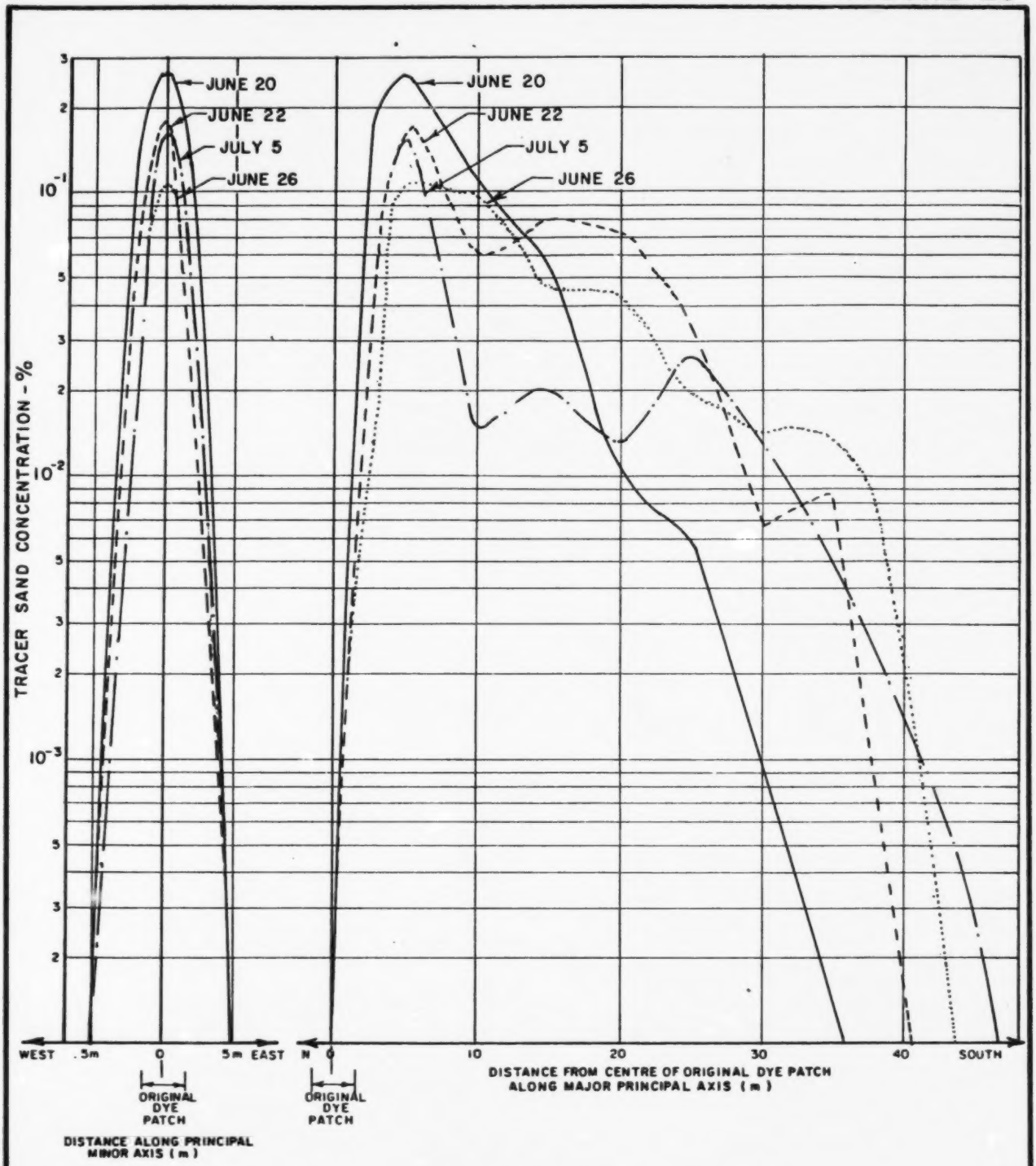


FRASER FORESHORE SEDIMENT STUDY

DIFFUSION RATES (m^2/day)

ADVECTION AND DIFFUSION RATES OF TRACER SAND

FIGURE 20



FRASER FORESHORE SEDIMENT STUDY

TIME VARIATION OF DYE CONCENTRATION TRANSECTS AT STATION 6

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

bdl 6639A-WCH nm83

APPENDICES

APPENDIX A

A FLUOROMETER CALIBRATION

Fluorometer Readings in ppb

10,000

1,000

100

10

Graph of normal fluorometer calibration on weight basis using 100 gm total samples

Results of calibration against normal grain count

Fraser Foreshore Sand and Silt
Fluorometric Calibration
Site 2

0.0001 0.001 0.01 0.1 1.0 10.0

gram of tracer Sand in 100 g. total SAND.

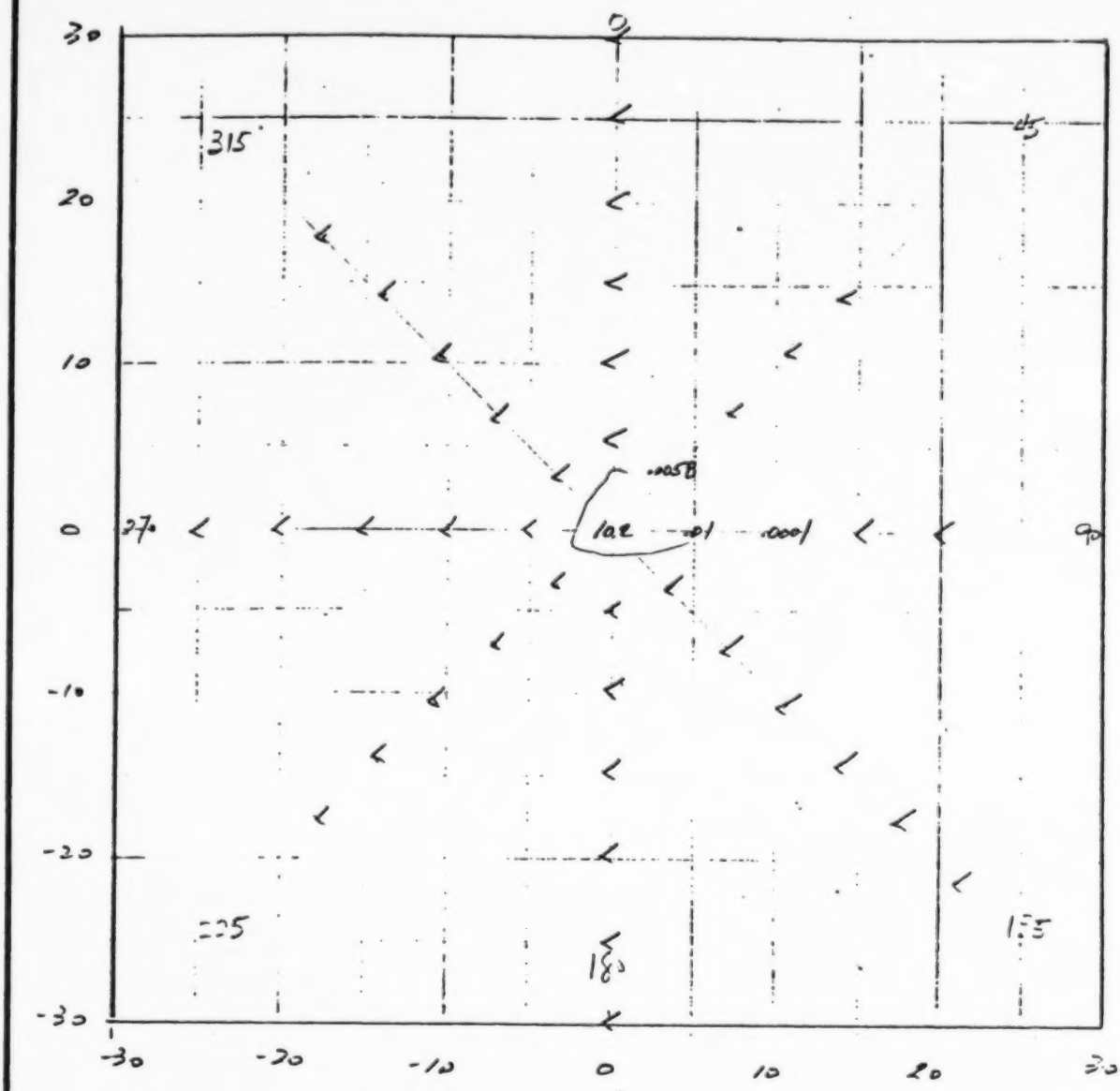
%

K&E LOGARITHMIC 3 X 5 CYCLES KEUFFEL & ESSER CO. 47 7520 MADE IN U.S.A.

APPENDIX B

TRACER SAND CONCENTRATION CONTOURS

STATION 1

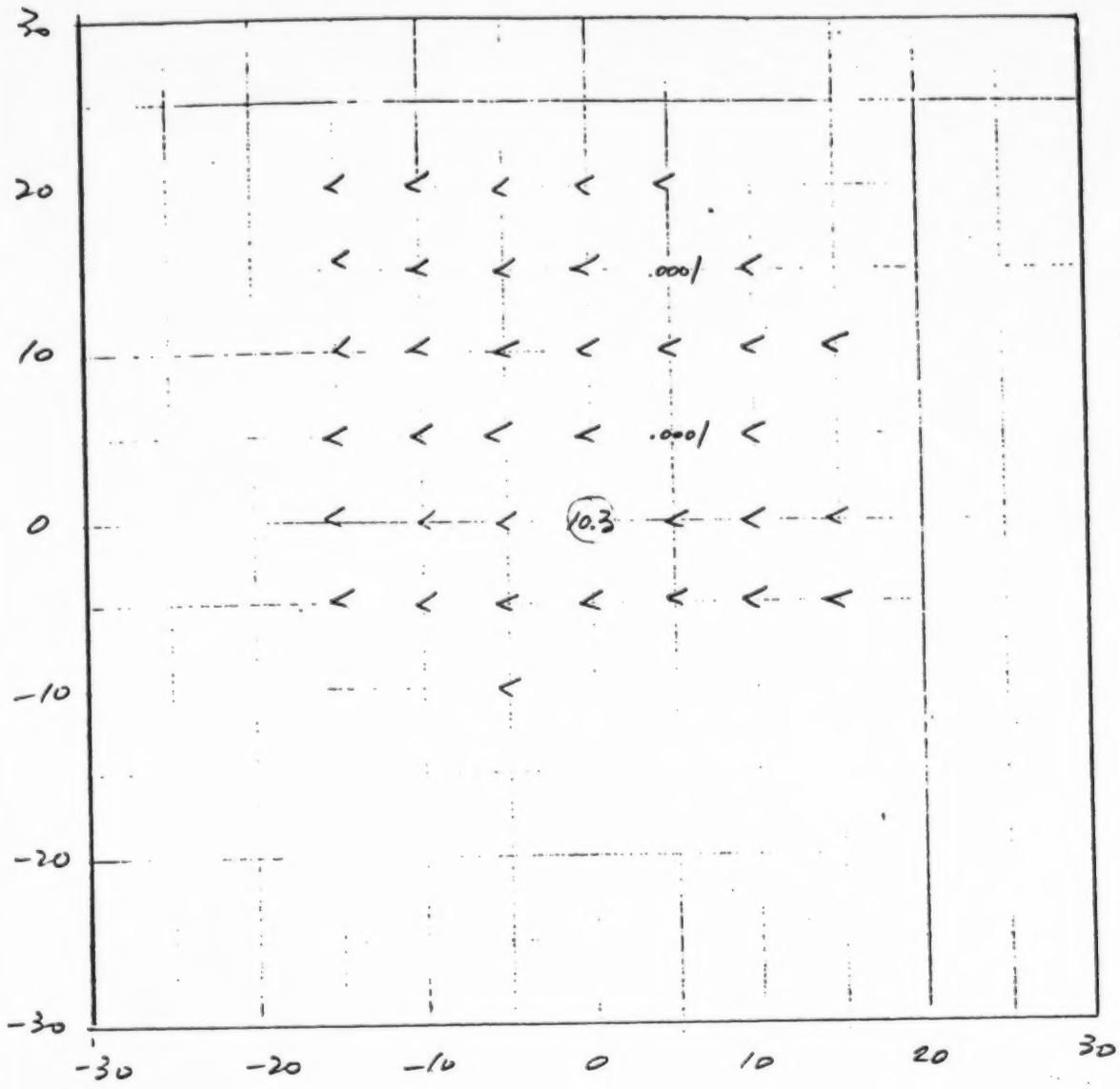


< = < .0001%

FRASER FORESHORE SEDIMENT
TRACER SAND CONCENTRATION
STATION : 1
DATE : 11th May 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.



< = <.0001 %

FRASER FORESHORE SEDIMENT

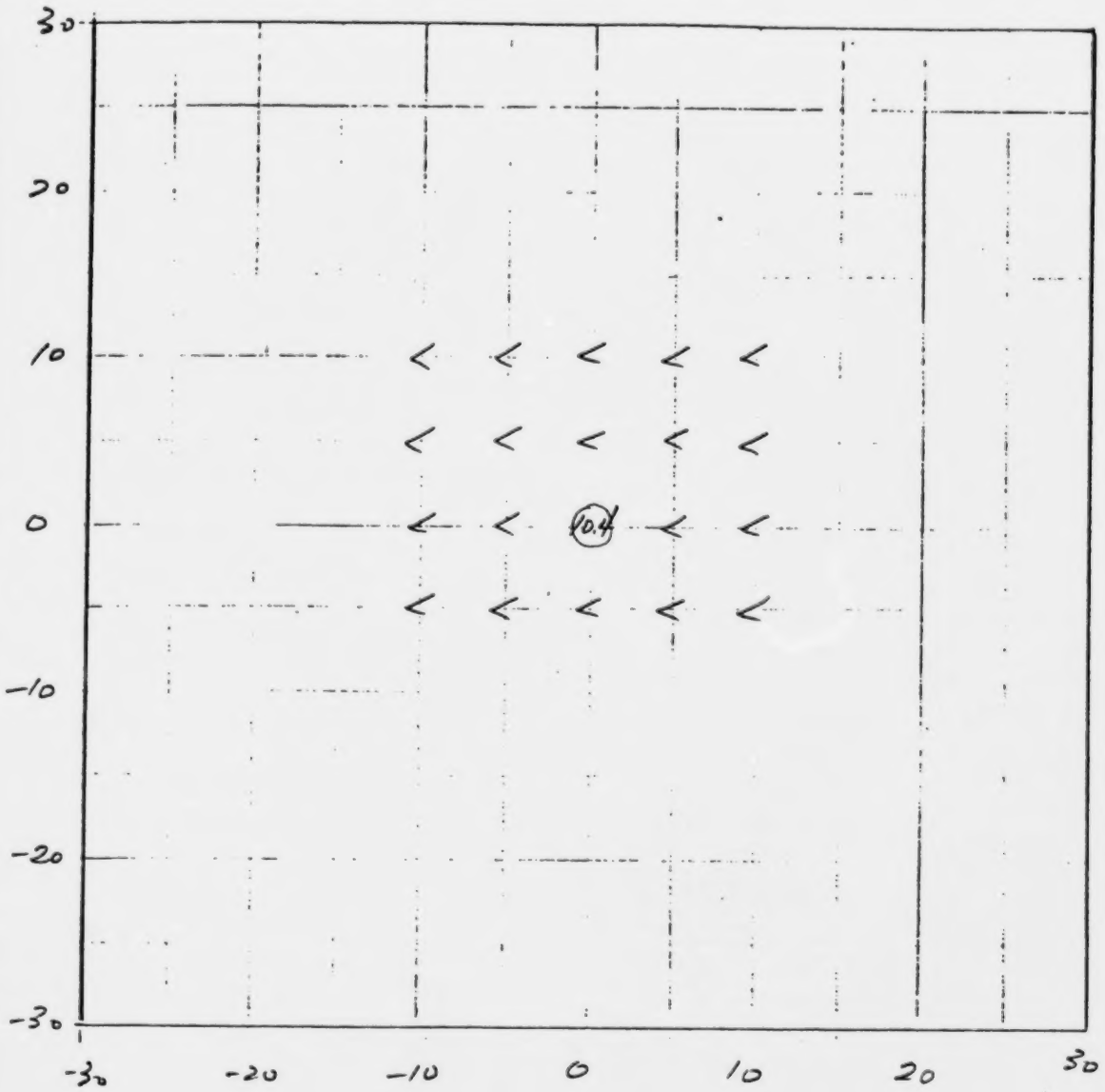
TRACER SAND CONCENTRATION

STATION : 1

DATE : 12th May 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.



$\angle = \angle .000 / \%$

FRASER FORESHORE SEDIMENT

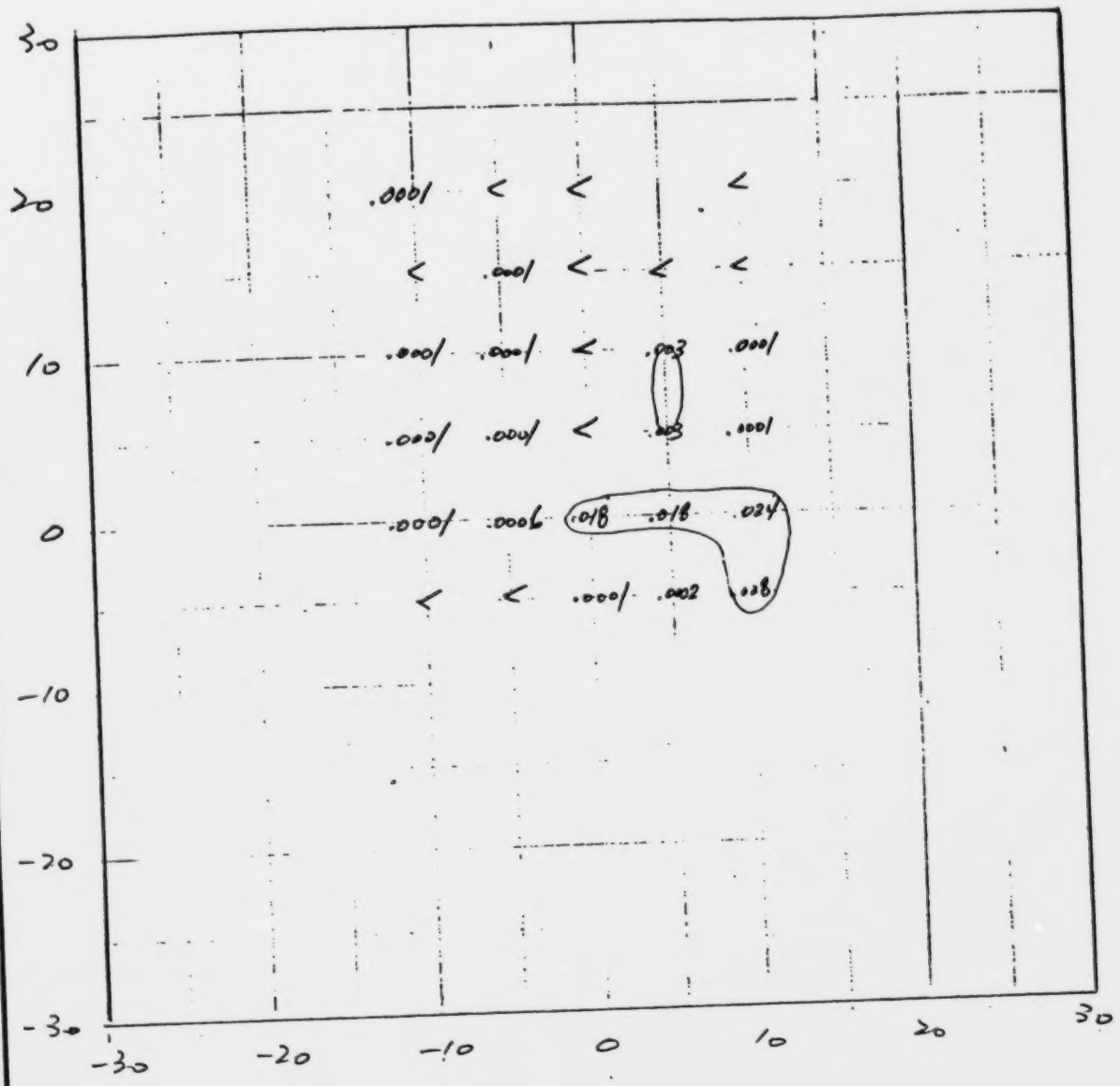
TRACER SAND CONCENTRATION

STATION : 1

DATE : 13th May 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.



< = < .0001%

FRASER FORESHORE SEDIMENT

TRACER SAND CONCENTRATION

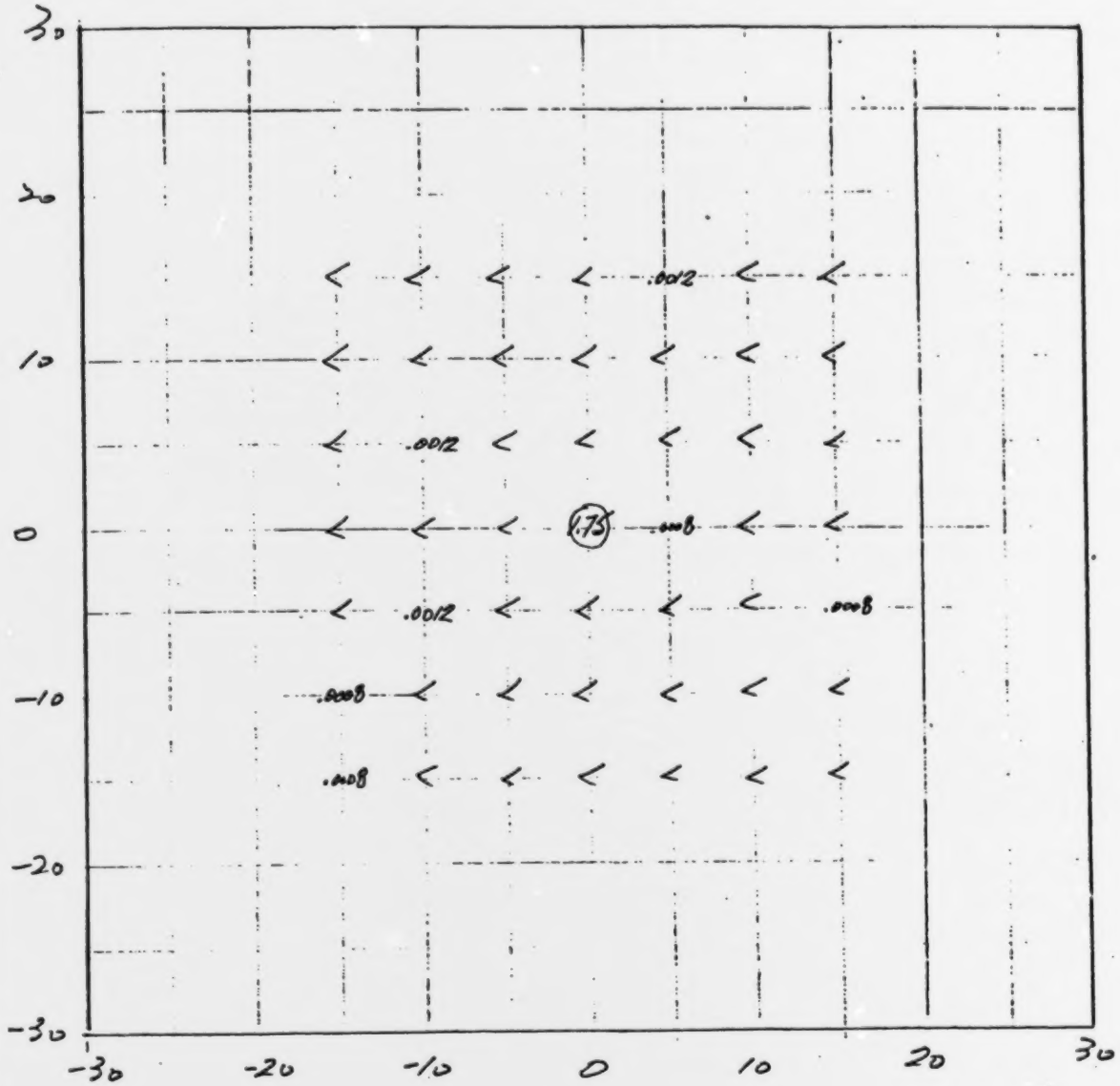
STATION : 1

DATE : 6th June 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

STATION 2

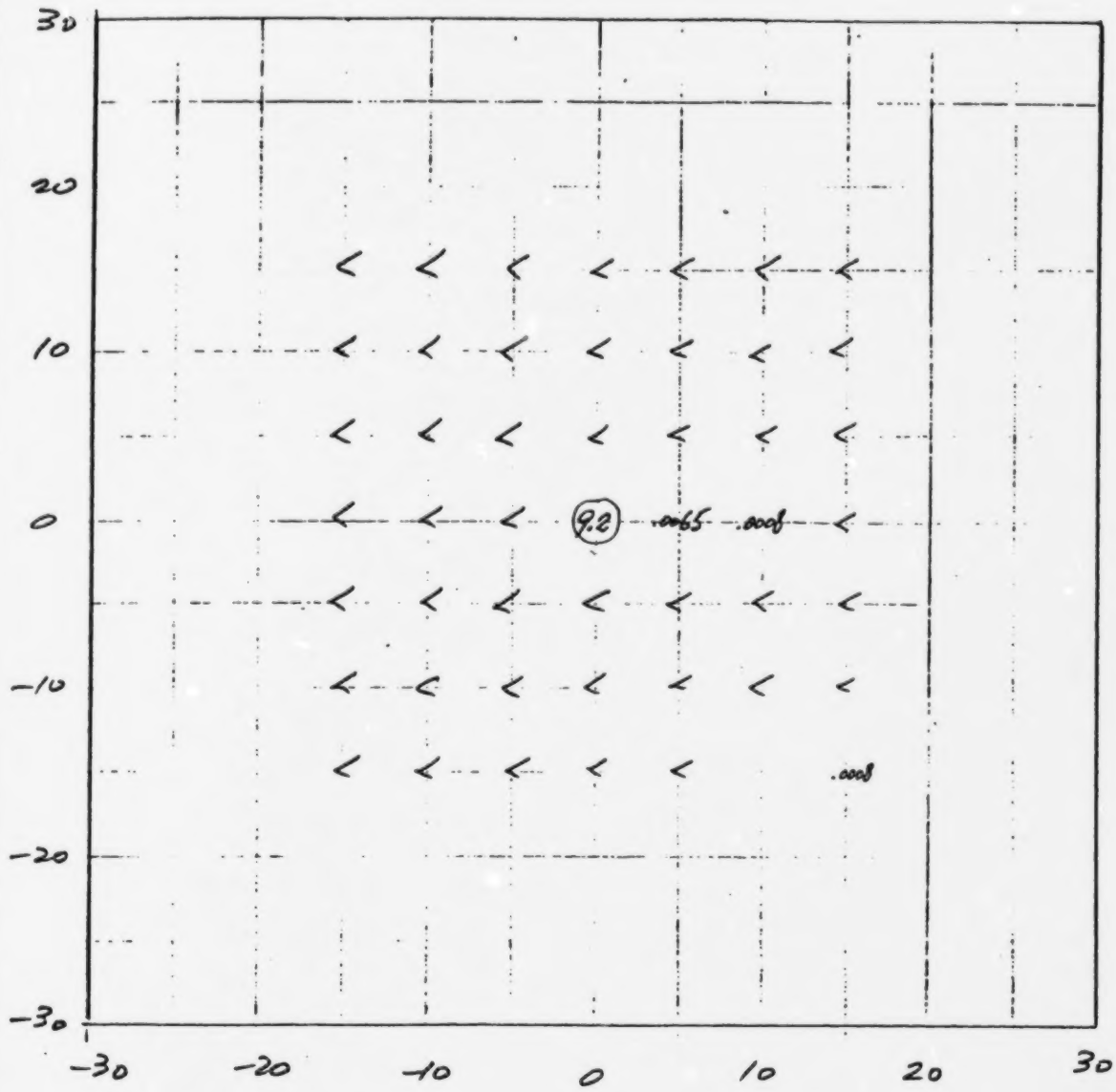


< = <.0008 %.

FRASER FORESHORE SEDIMENT
TRACER SAND CONCENTRATION
STATION : 2
DATE : 10th JUNE 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.



No significant sand movement. < = <.0008%

FRASER FORESHORE SEDIMENT

TRACER SAND CONCENTRATION

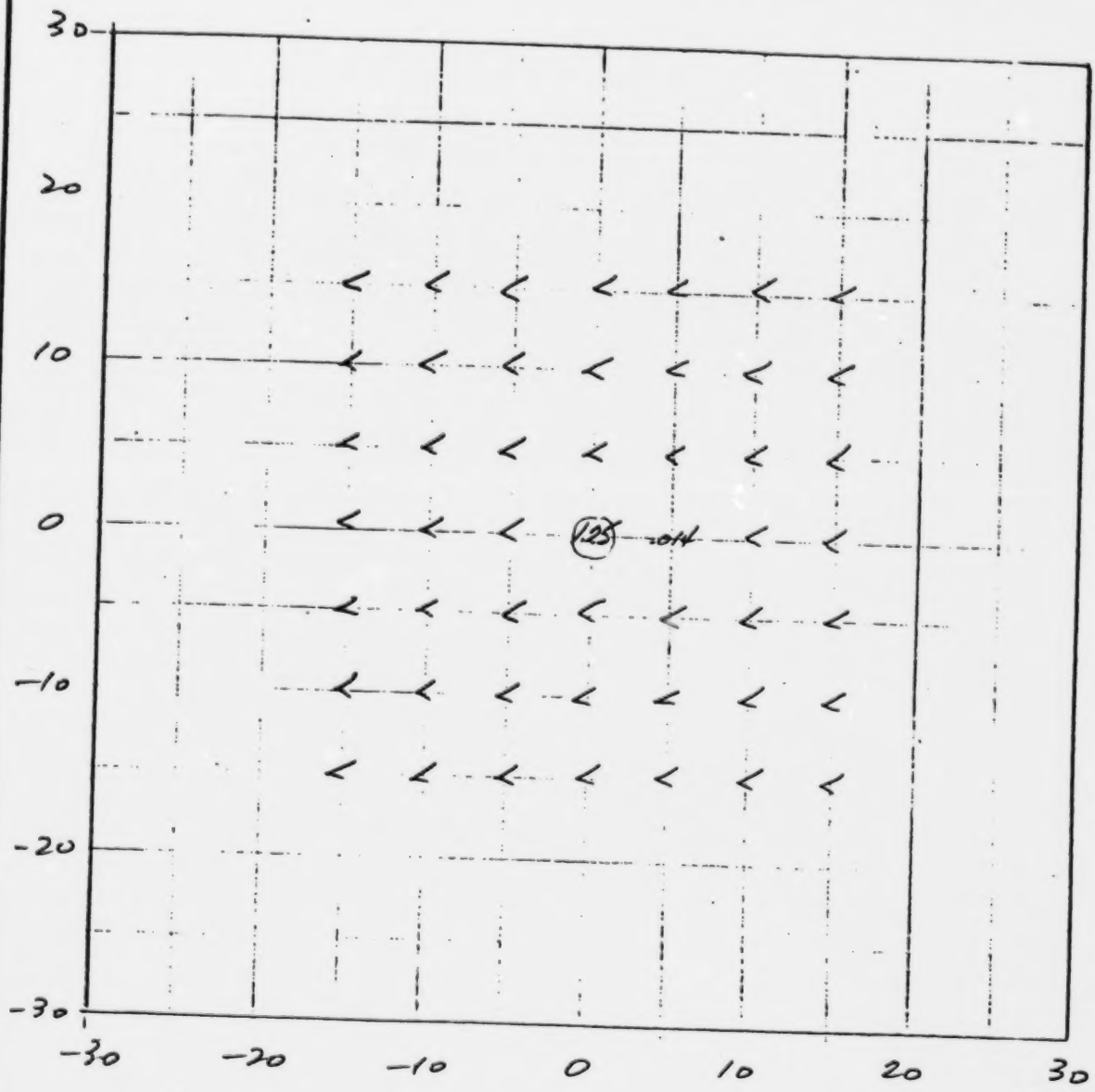
STATION : 2

DATE : 19th JUNE 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

bril463RA-WCH



< = 1.0008%.

FRASER FORESHORE SEDIMENT
TRACER SAND CONCENTRATION

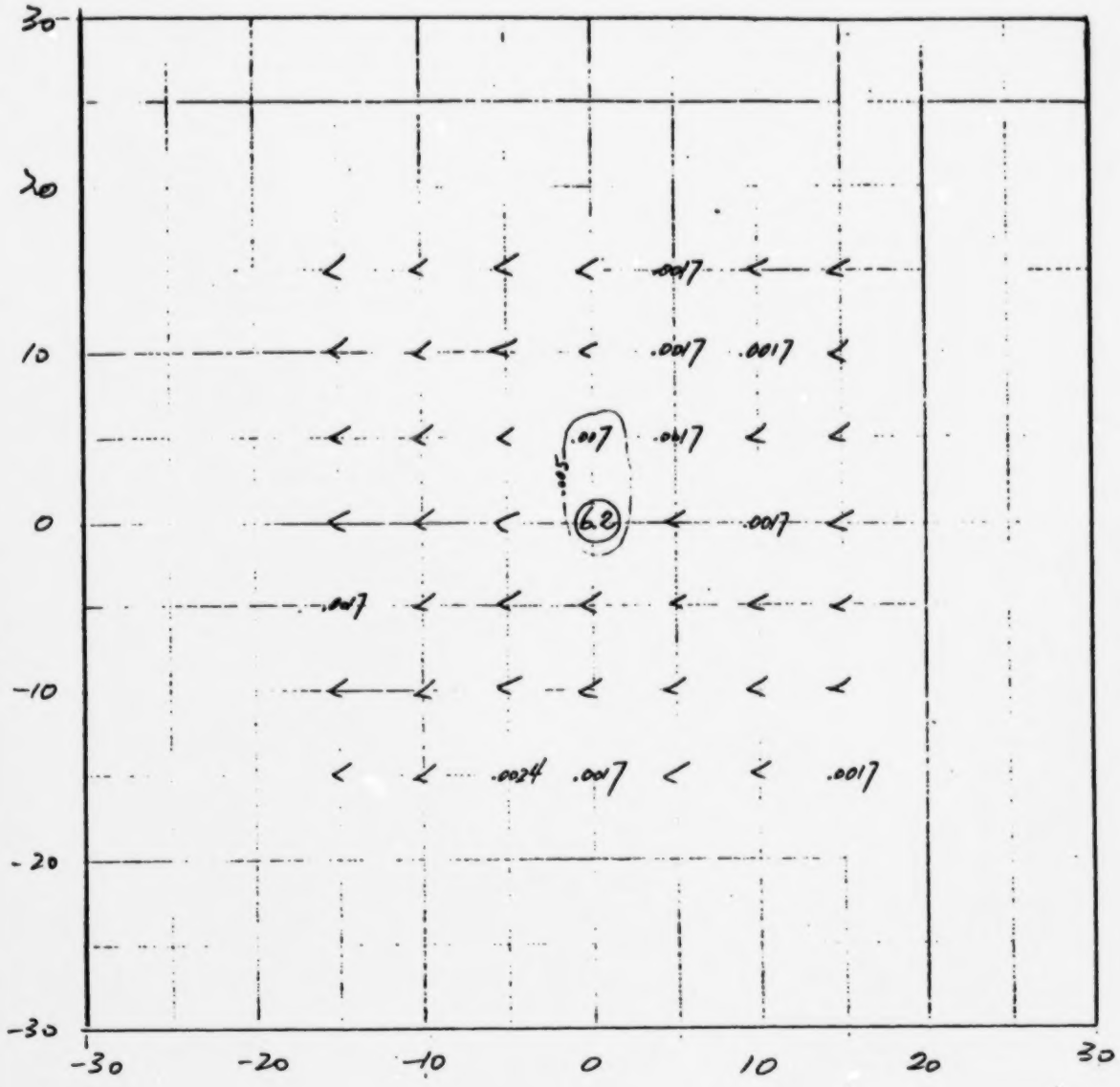
Scale 1:400

STATION : 2

DATE : 24th June 82

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

STATION 3



< = <.0017 %

FRASER FORESHORE SEDIMENT

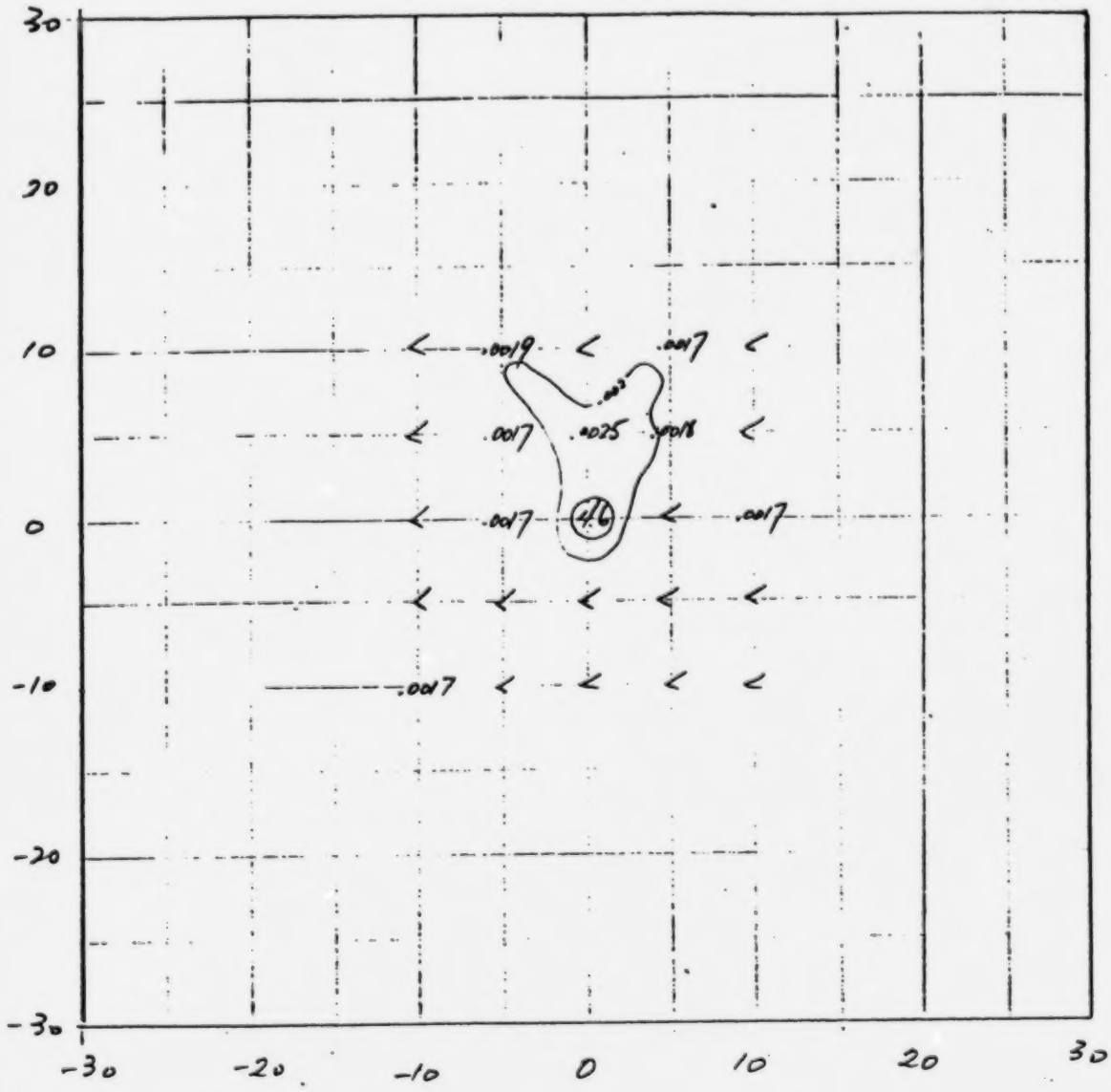
TRACER SAND CONCENTRATION

STATION : 3

DATE : 9th JUNE 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

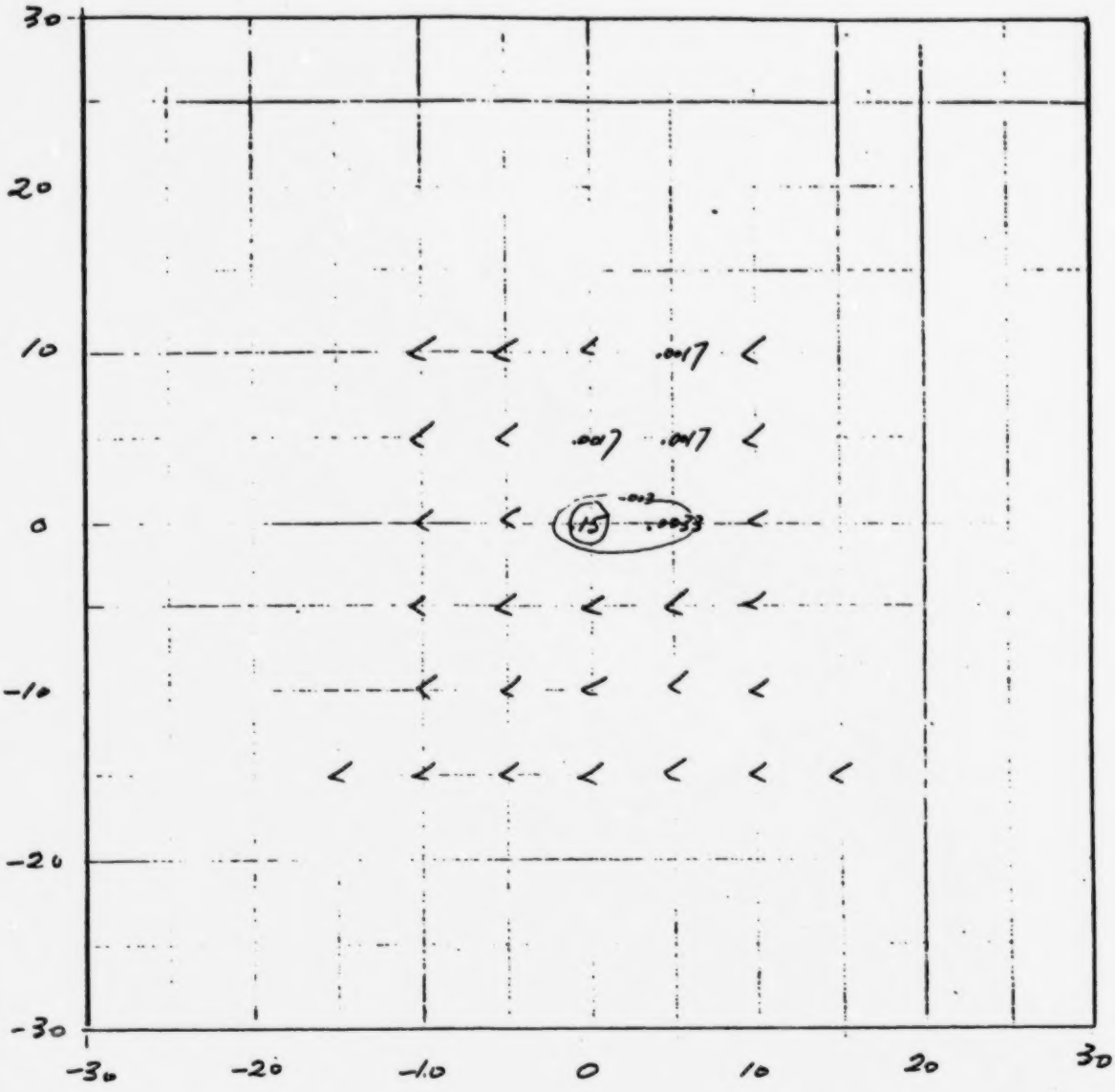


< = <.0017%

FRASER FORESHORE SEDIMENT
TRACER SAND CONCENTRATION
STATION: 3
DATE: 10th JUNE 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.



< = <.0017%

FRASER FORESHORE SEDIMENT

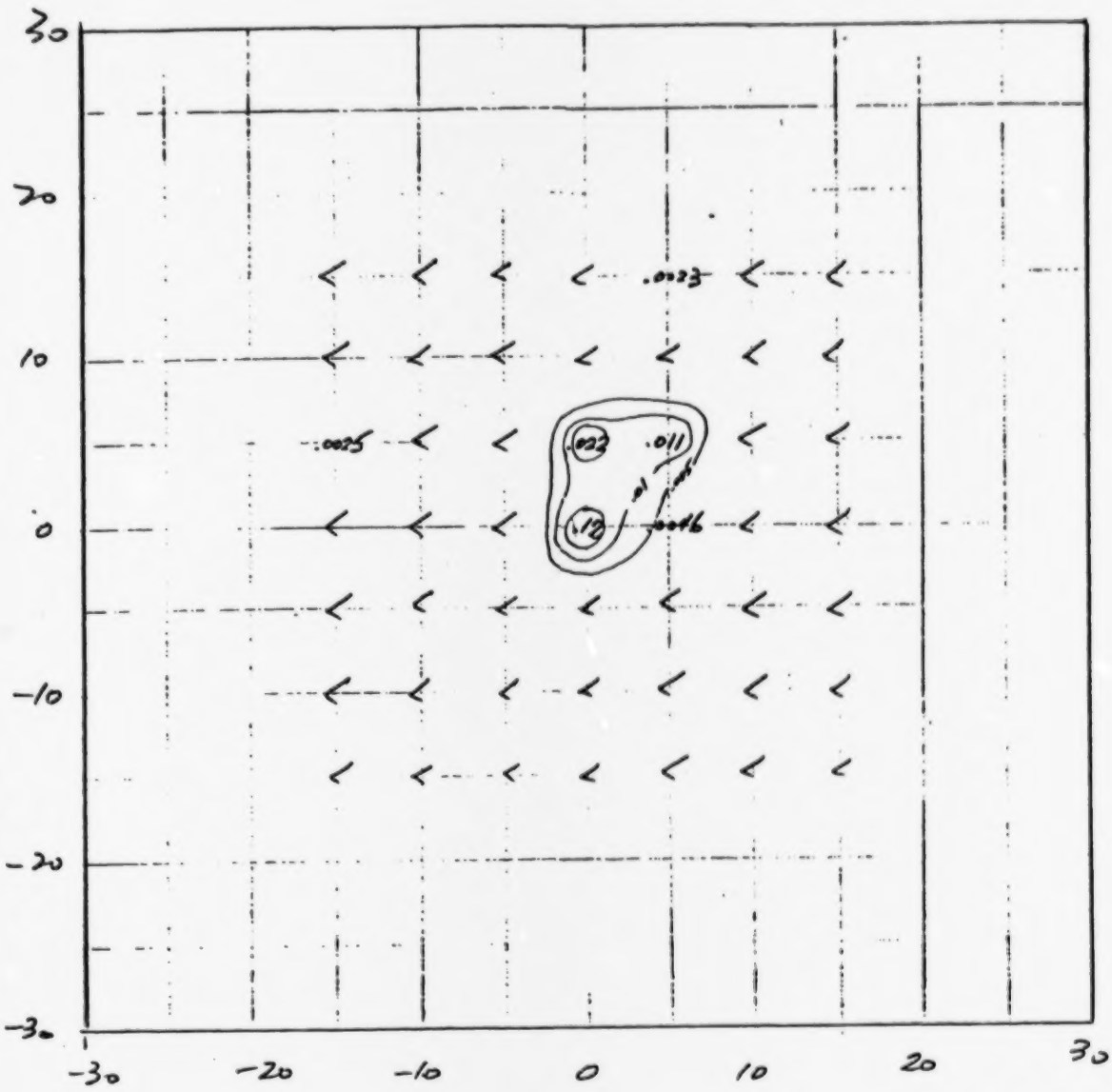
TRACER SAND CONCENTRATION

STATION : 3

DATE : 19th JUNE 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.



< = <.0017%

FRASER FORESHORE SEDIMENT

TRACER SAND CONCENTRATION

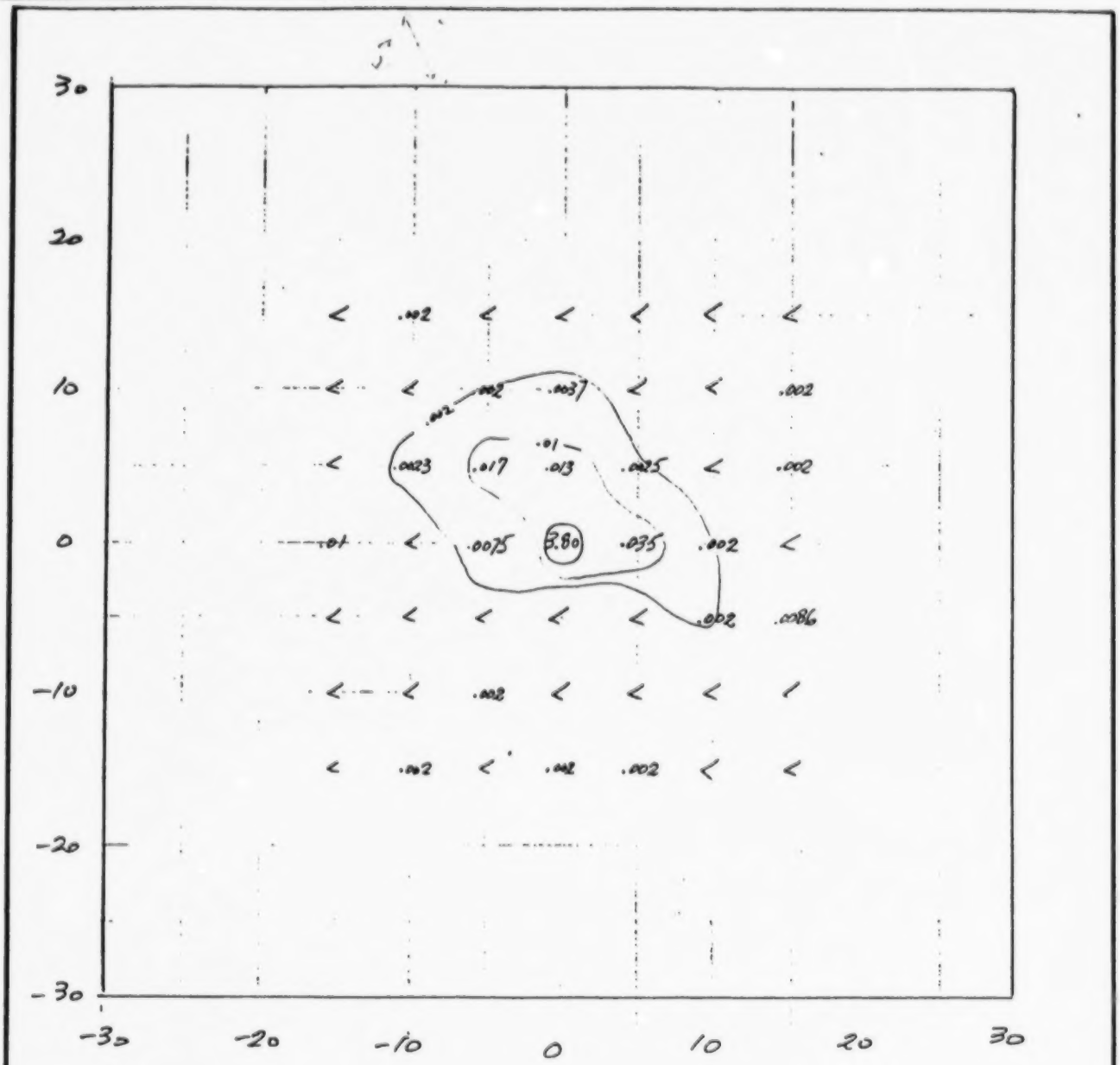
STATION : 3

DATE : 24th JUNE 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

STATION 4



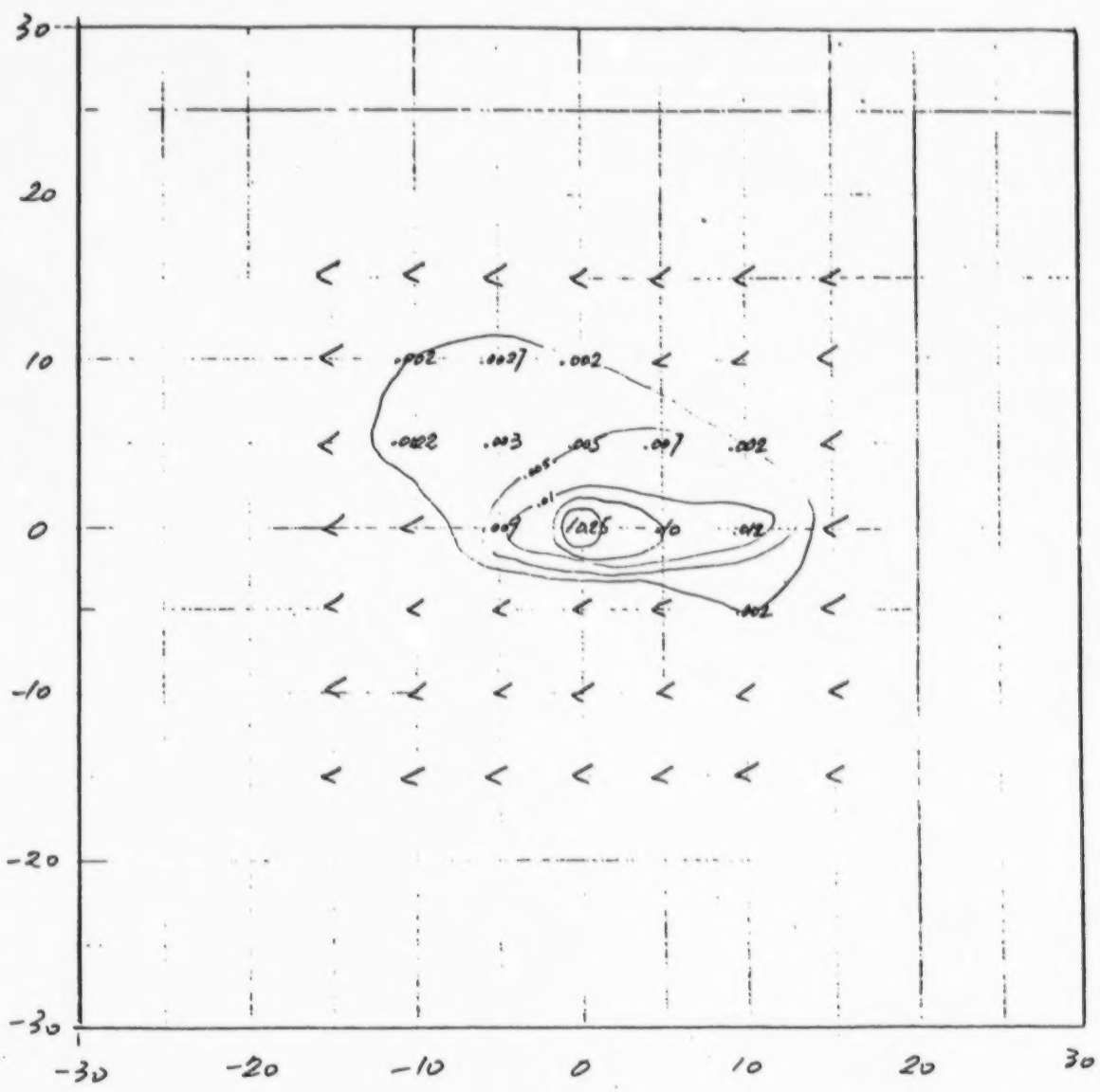
< = < .002 %

FRASER FORESHORE SEDIMENT
TRACER SAND CONCENTRATION
STATION : 4
DATE : 8th July 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

bil 0039A-WCH



< = < .002 %

FRASER FORESHORE SEDIMENT

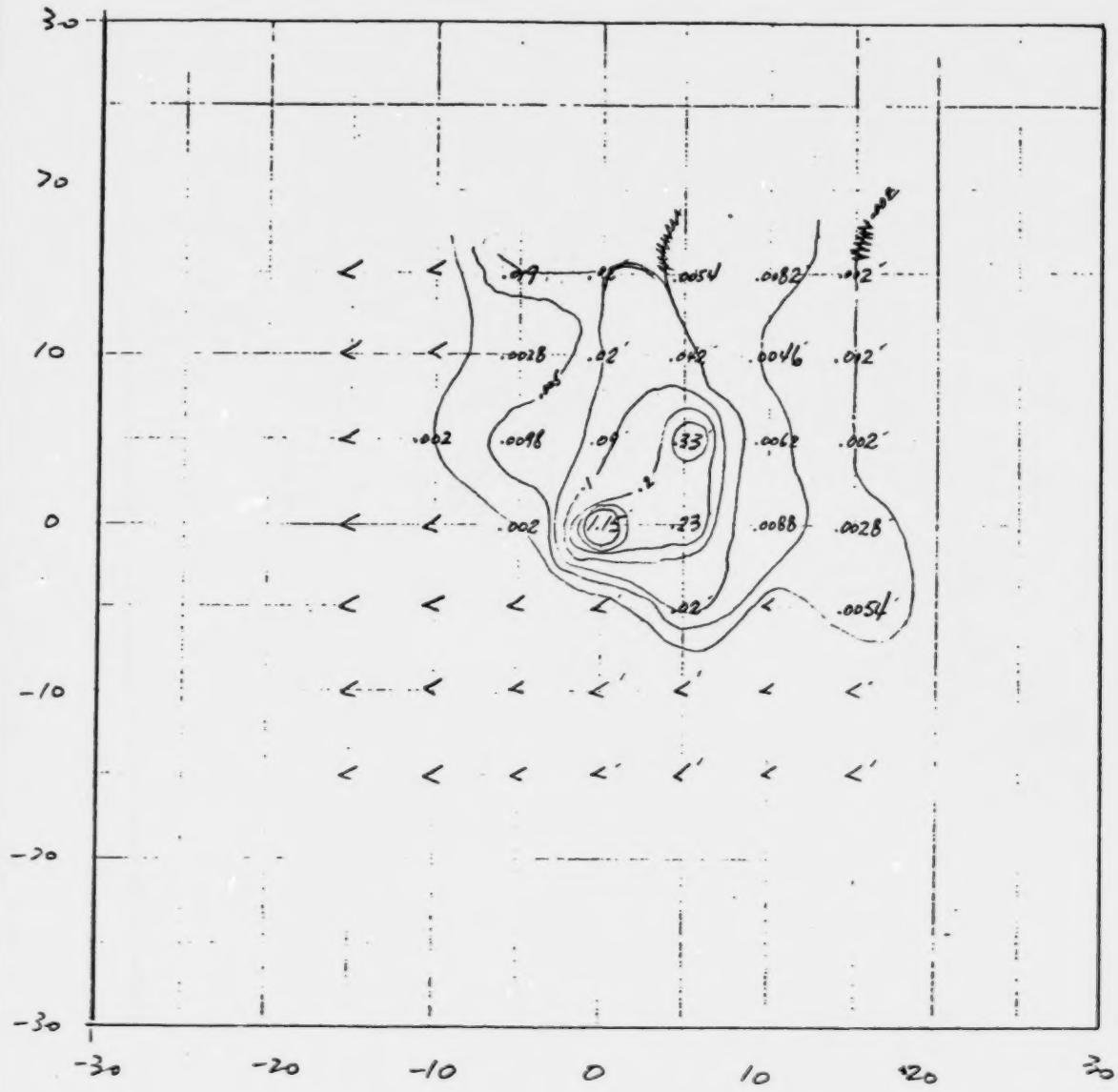
TRACER SAND CONCENTRATION

STATION : 4

DATE : 10th July 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.



< = <.002%

FRASER FORESHORE SEDIMENT

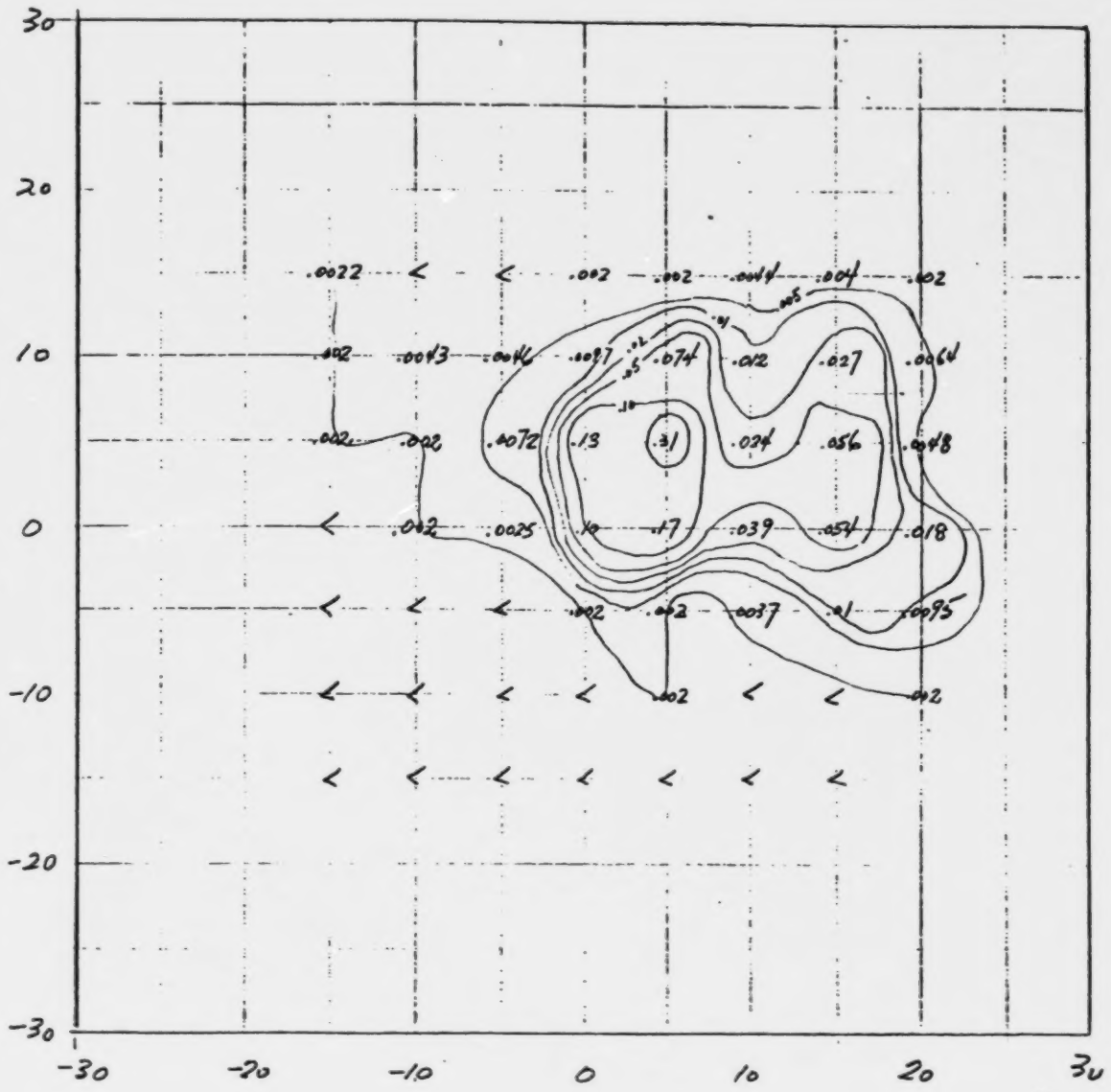
TRACER SAND CONCENTRATION

STATION : 4

DATE : 18TH July 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.



< = < .002 %

FRASER FORESHORE SEDIMENT

TRACER SAND CONCENTRATION

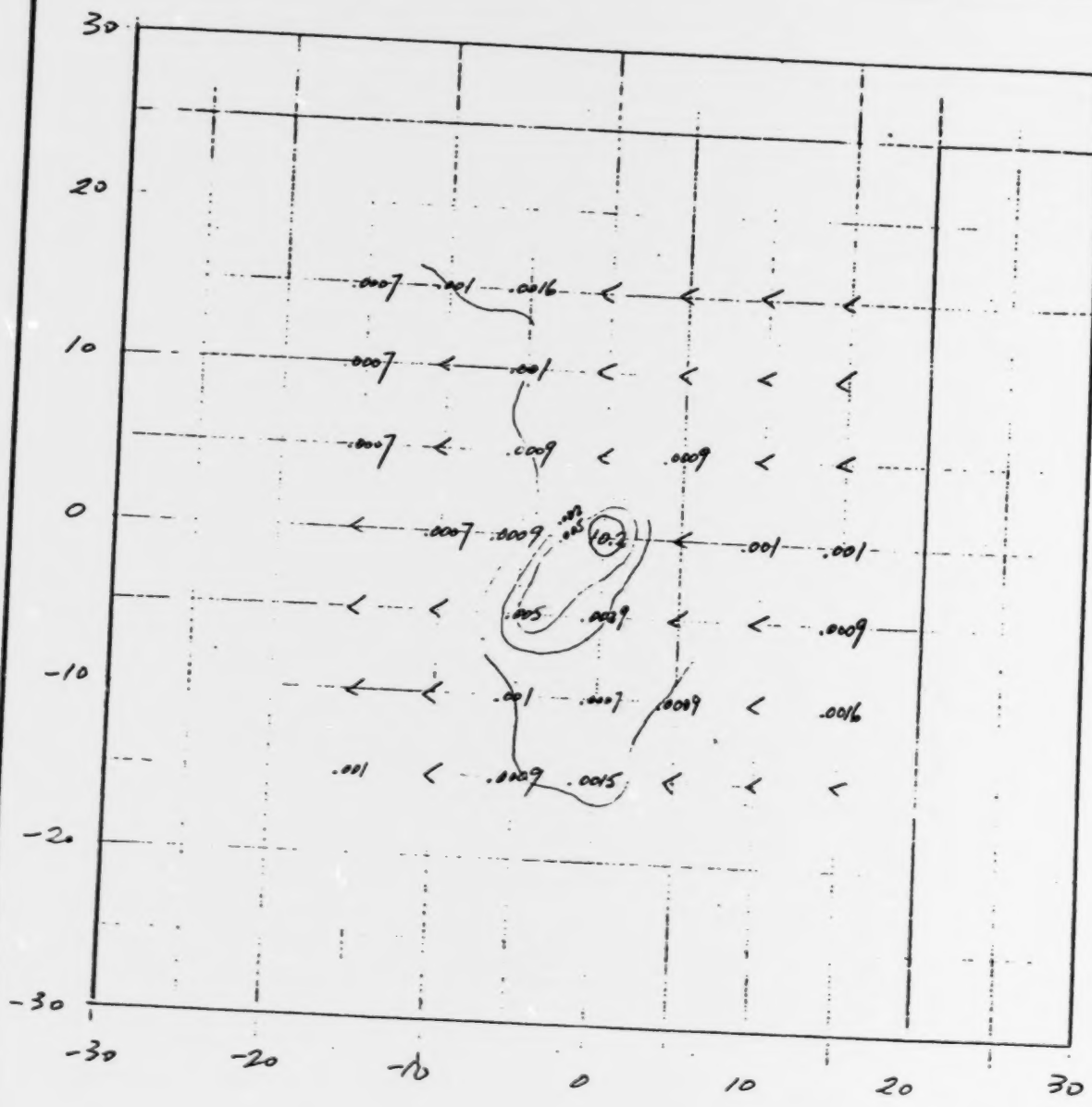
STATION : 4

DATE : 23 July 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

STATION 5



< = <.0007 %

FRASER FORESHORE SEDIMENT

TRACER SAND CONCENTRATION

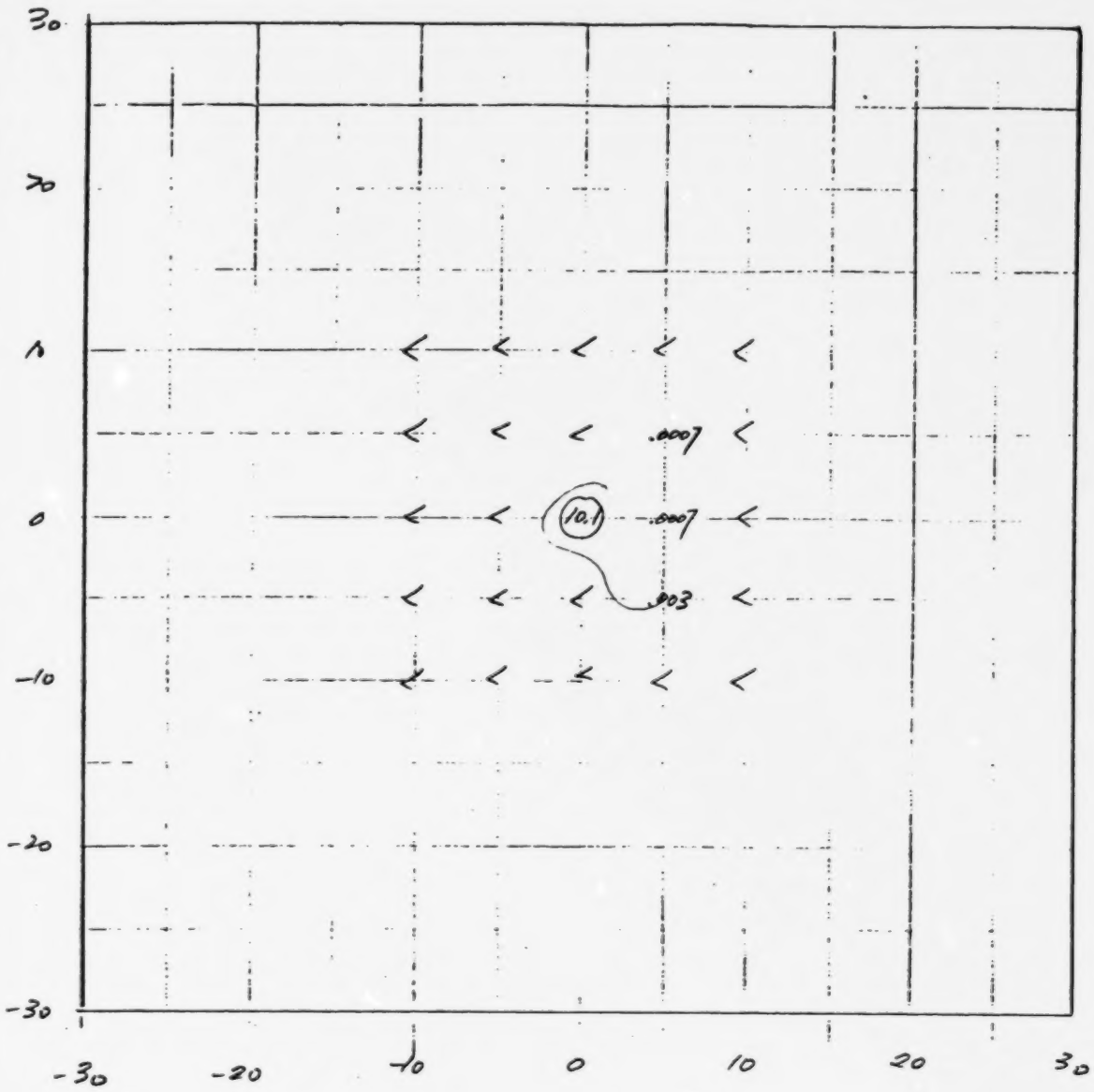
Scale 1:400

STATION : 5

DATE : 8th July 82

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

bil 6639A-WCH



$< = < .0007\ \%$

FRASER FORESHORE SEDIMENT

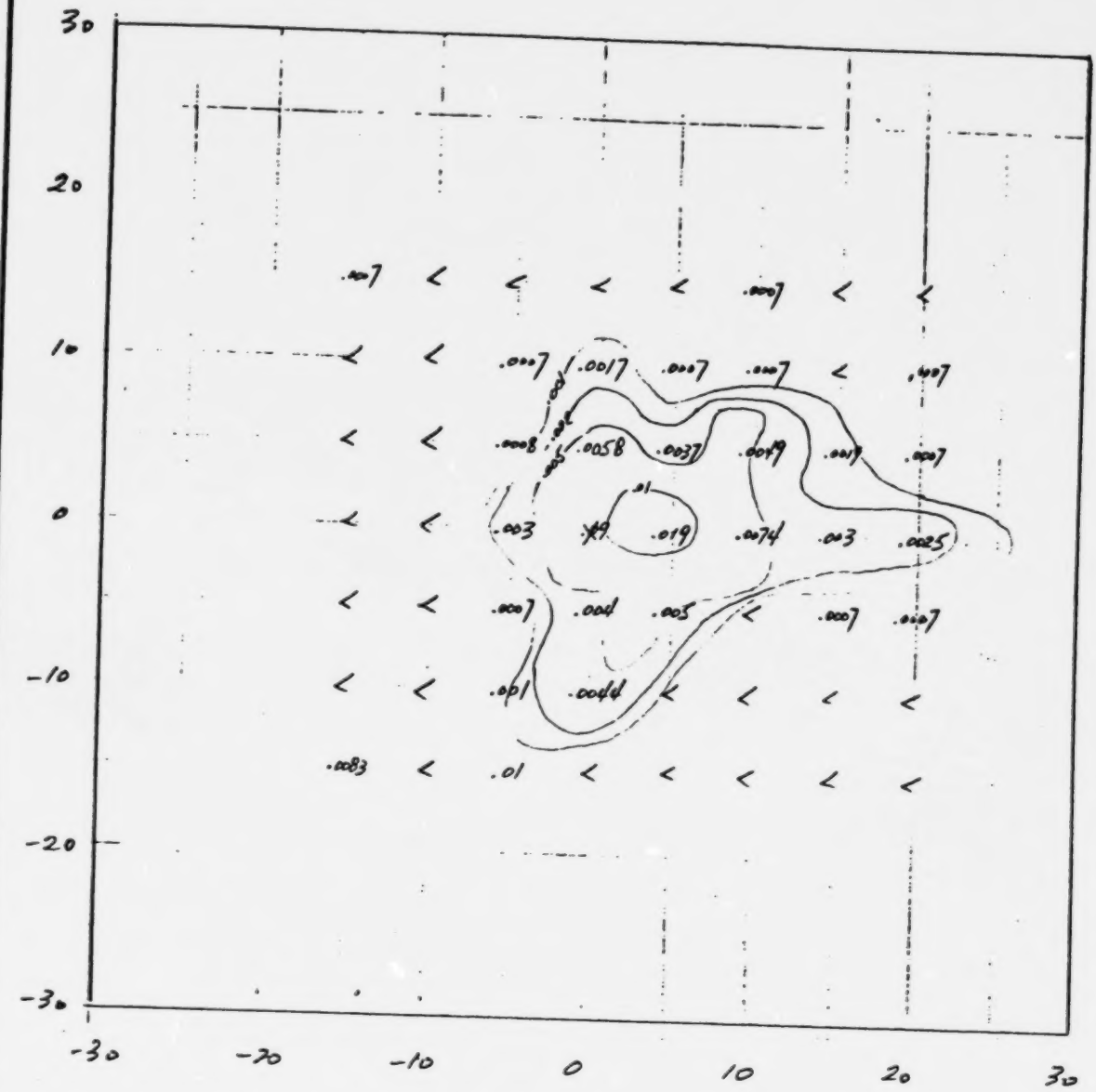
TRACER SAND CONCENTRATION

STATION : 5

DATE : 10 July 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.



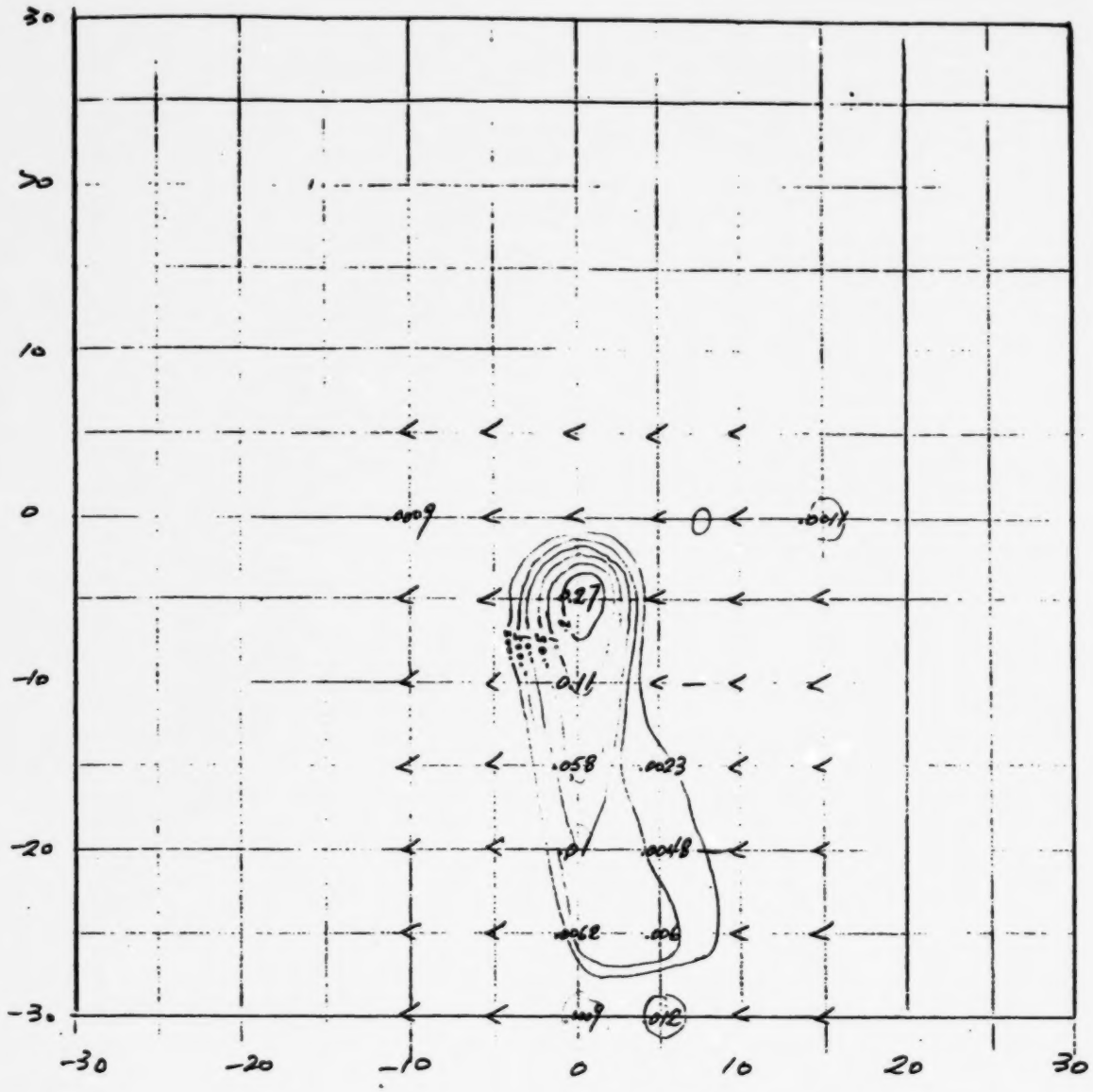
< = <.0007%

Scale 1:400

FRASER FORESHORE SEDIMENT
TRACER SAND CONCENTRATION
STATION : 5
DATE : 23rd July 82

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

STATION 6

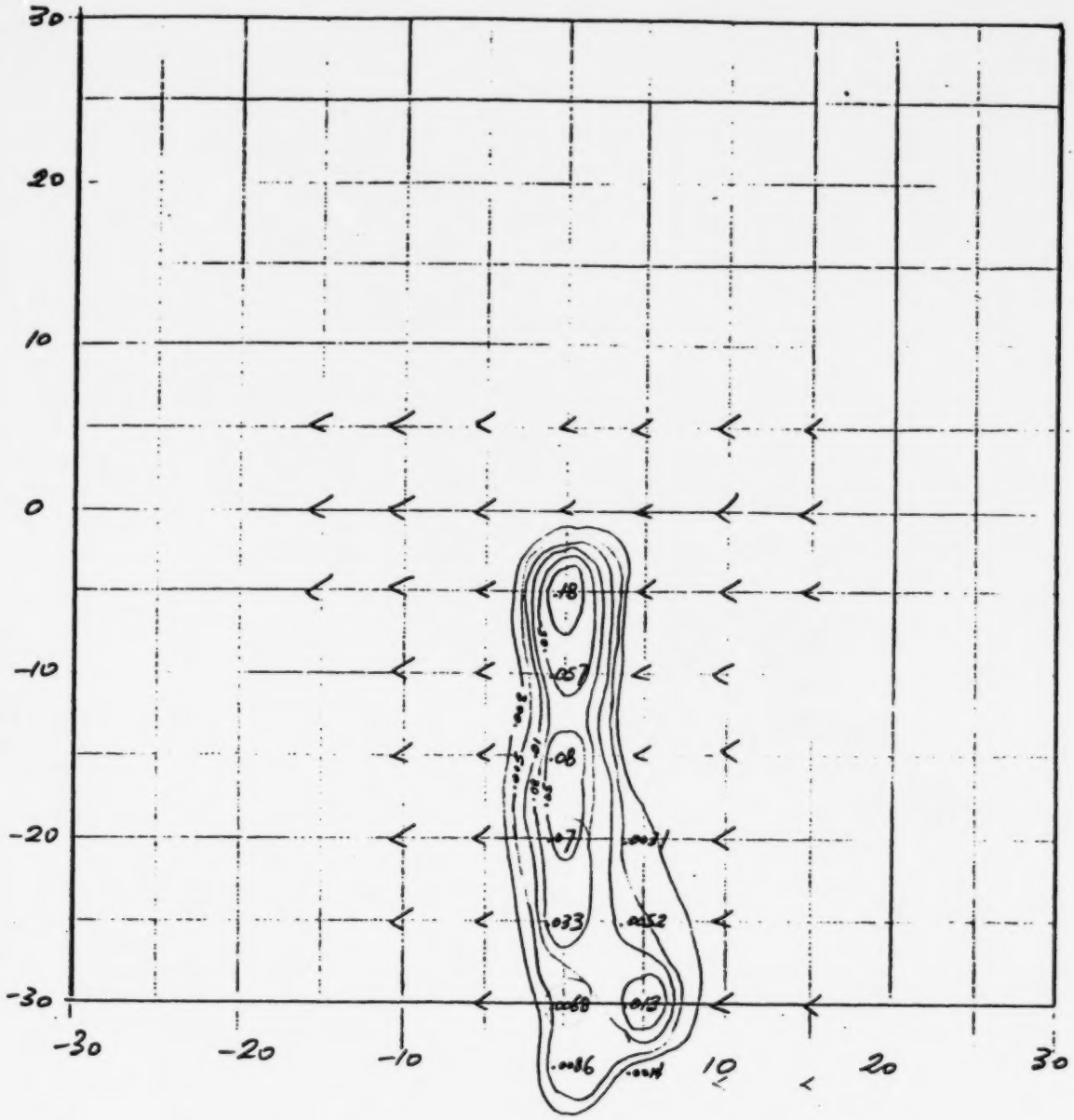


< = <.0009 %

FRASER FORESHORE SEDIMENT
TRACER SAND CONCENTRATION
STATION : 6
DATE : 20 JUNE 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.



< = <.0009 %

FRASER FORESHORE SEDIMENT

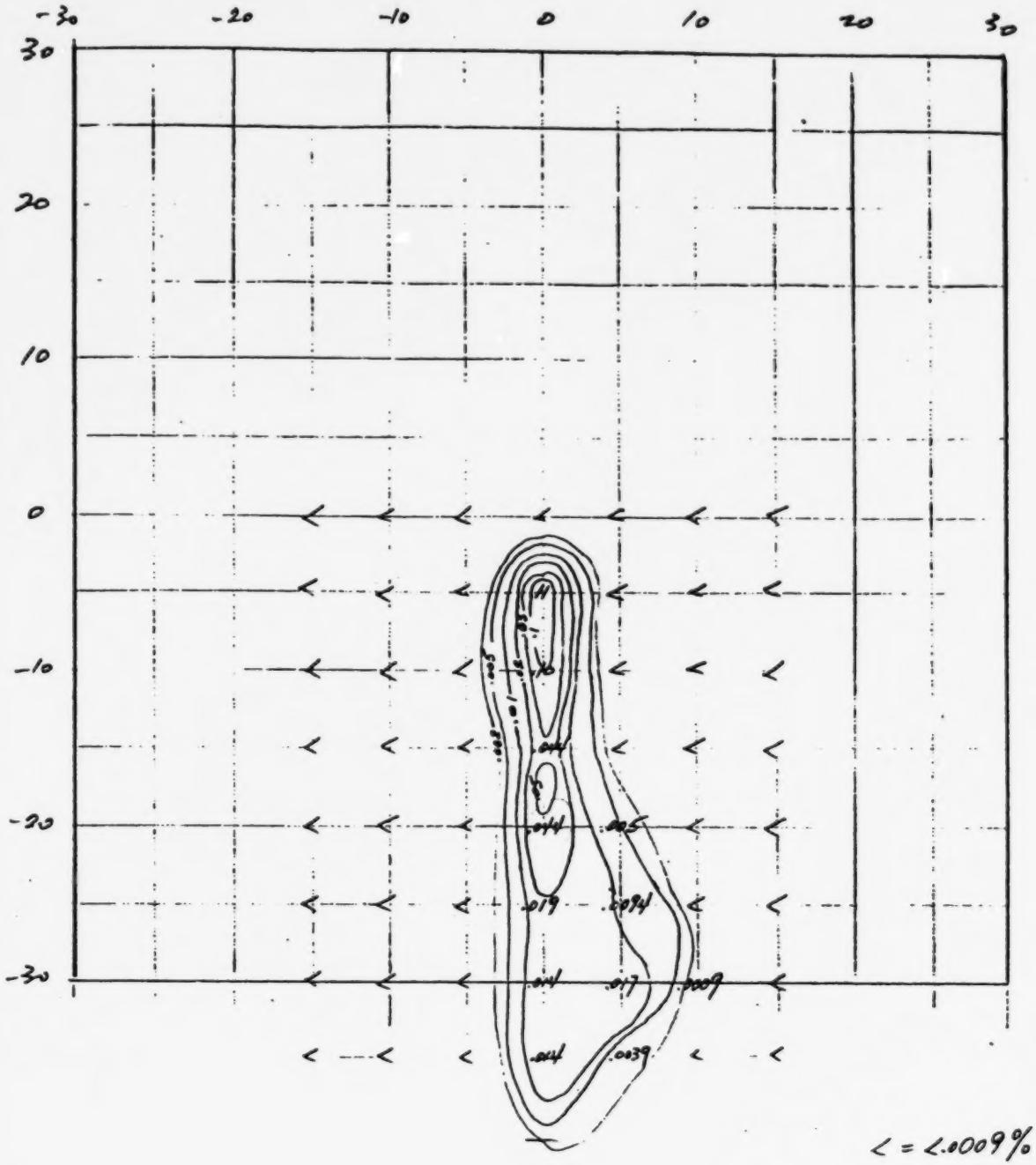
TRACER SAND CONCENTRATION

STATION : 6

DATE : 22nd JUNE 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.



< = <.0009%

FRASER FORESHORE SEDIMENT

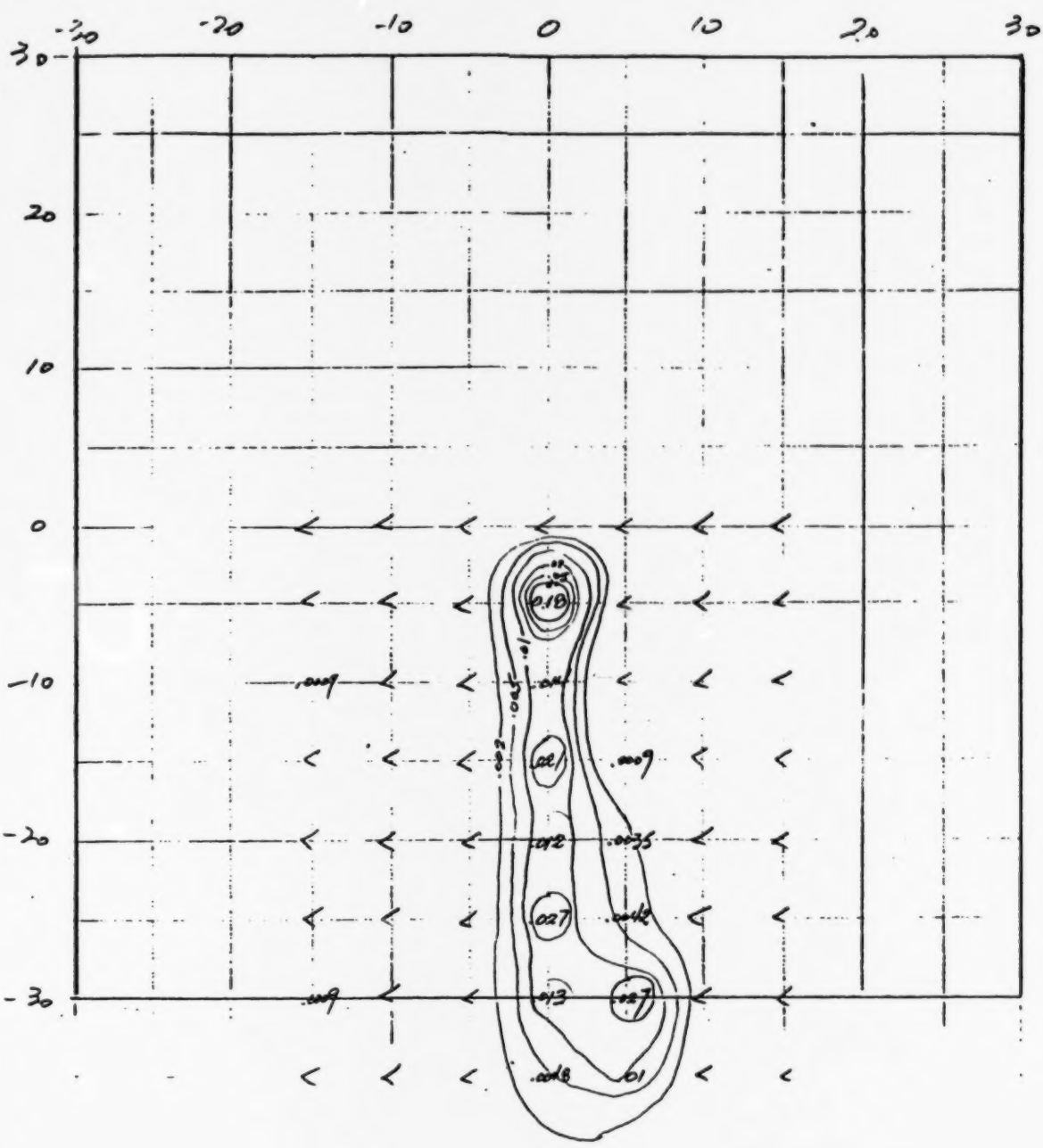
TRACER SAND CONCENTRATION

STATION : 6

DATE : 26th JUNE 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.



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FRASER FORESHORE SEDIMENT

TRACER SAND CONCENTRATION

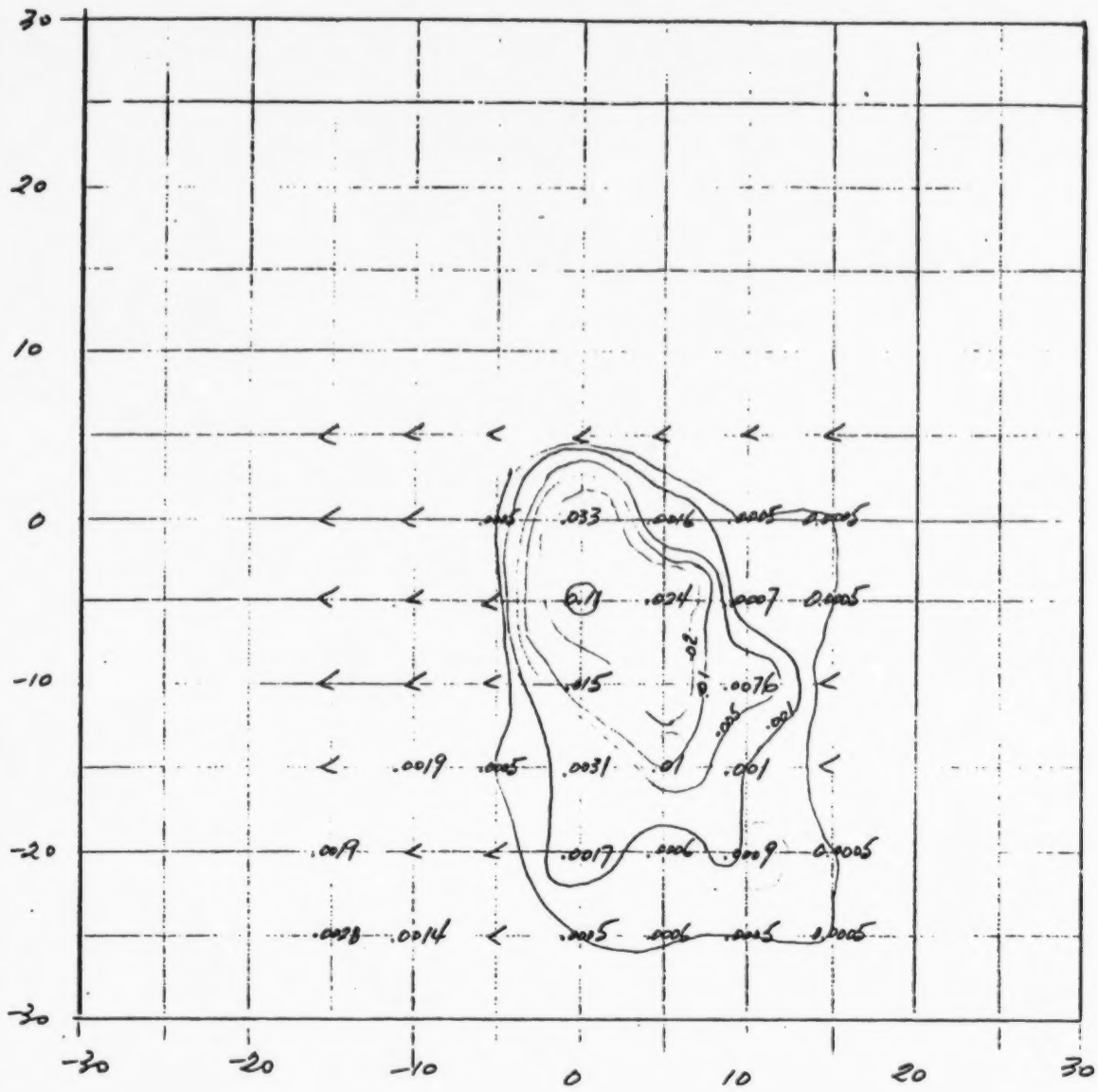
STATION : 6

DATE : 5th July 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

STATION 7



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FRASER FORESHORE SEDIMENT

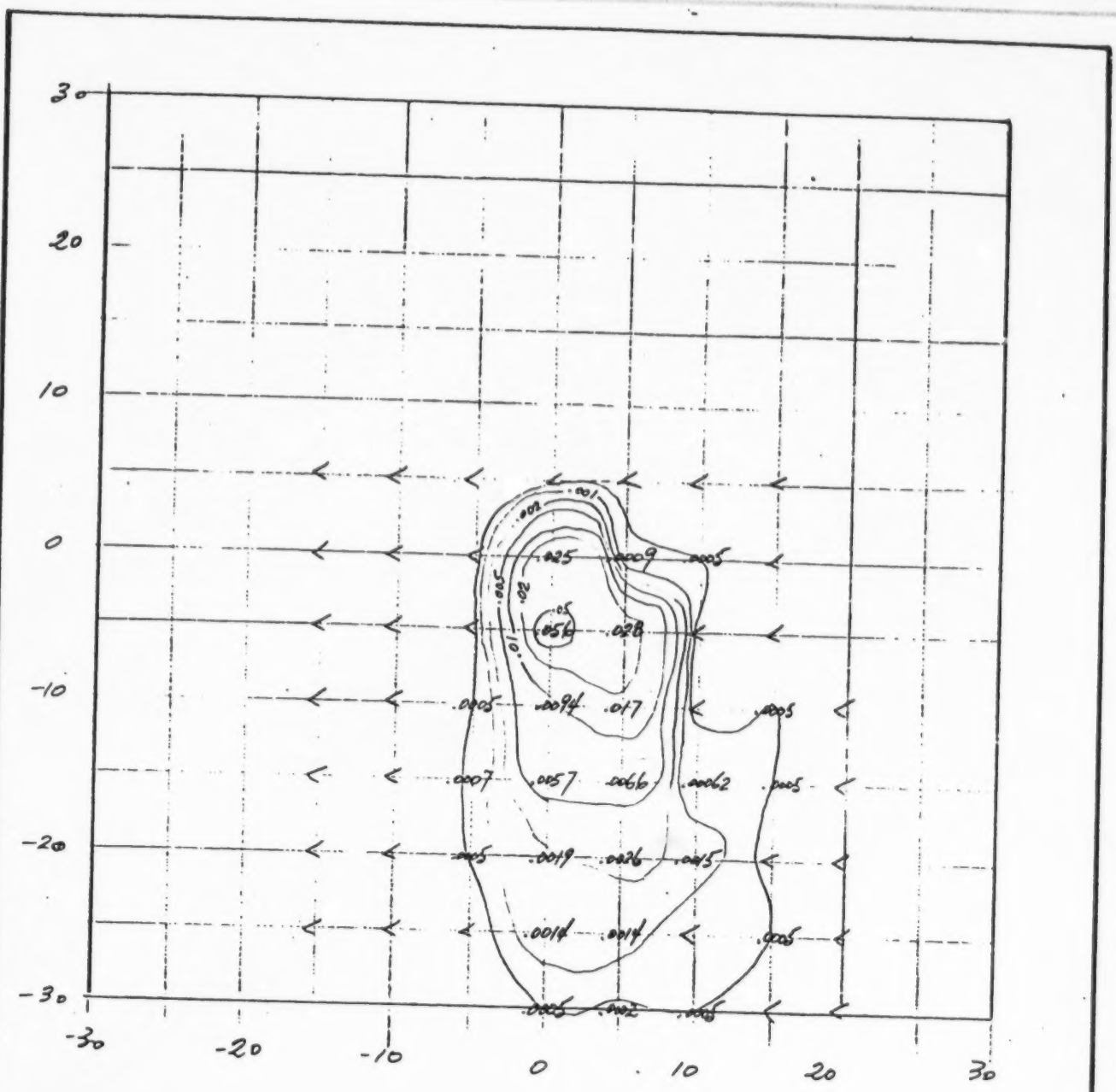
TRACER SAND CONCENTRATION

STATION : 7

DATE : 21st. June 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.



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FRASER FORESHORE SEDIMENT

TRACER SAND CONCENTRATION

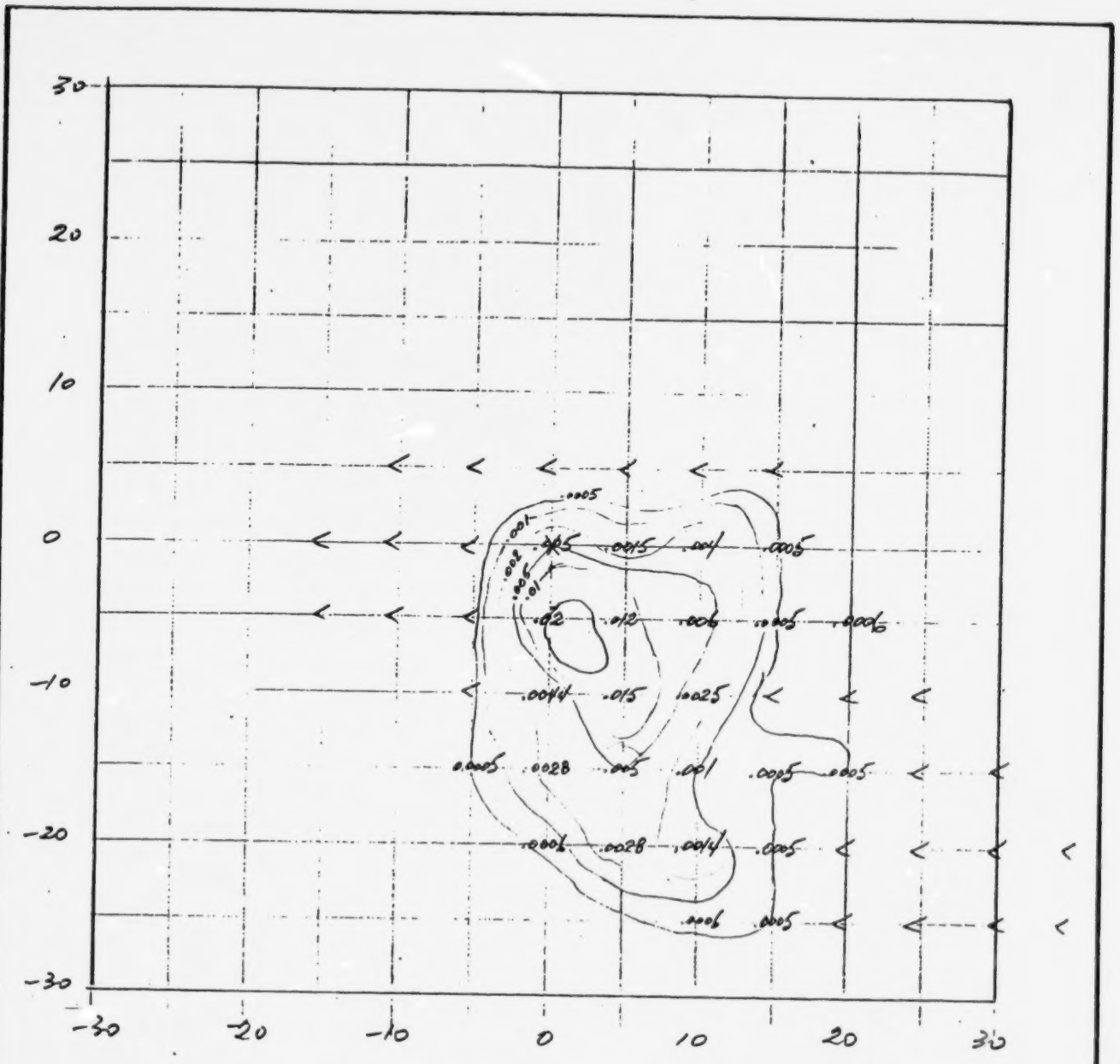
STATION : 7

DATE : 22nd June 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

52



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FRASER FORESHORE SEDIMENT

TRACER SAND CONCENTRATION

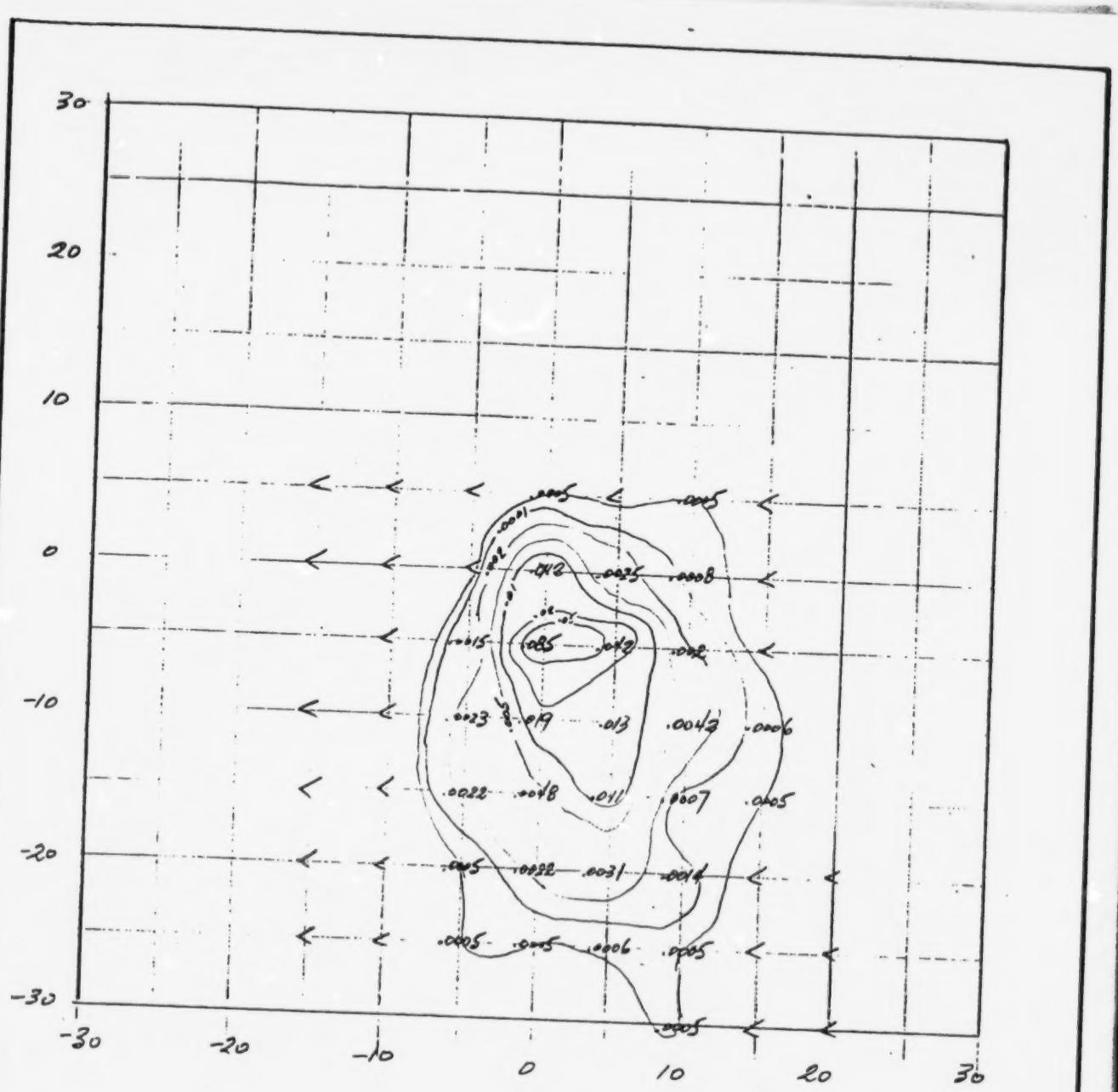
STATION : 7

DATE : 26th JUNE 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

53



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FRASER FORESHORE SEDIMENT

TRACER SAND CONCENTRATION

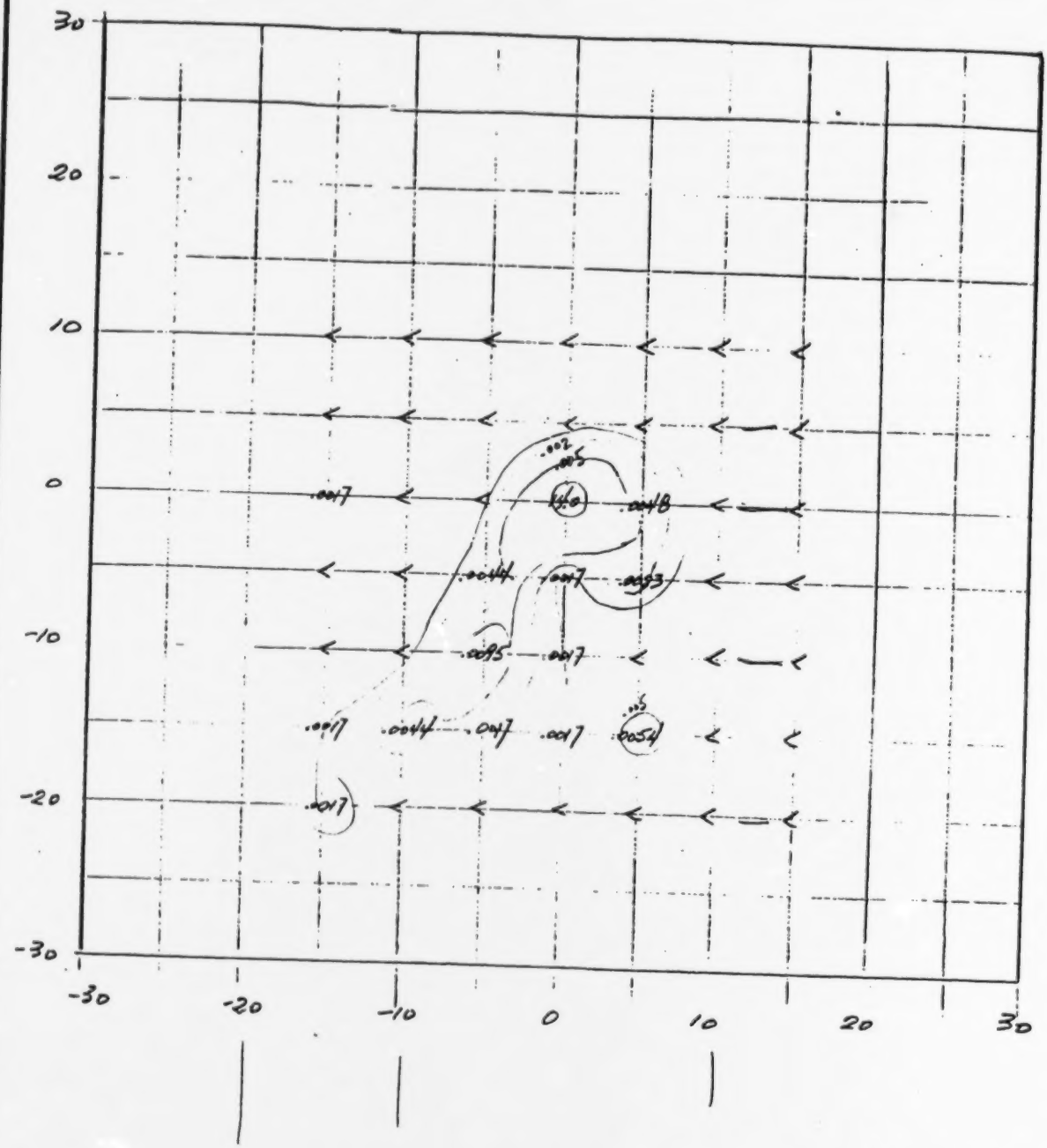
Scale 1:400

STATION : 7

DATE : 5th July 82

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

STATION 8



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FRASER FORESHORE SEDIMENT

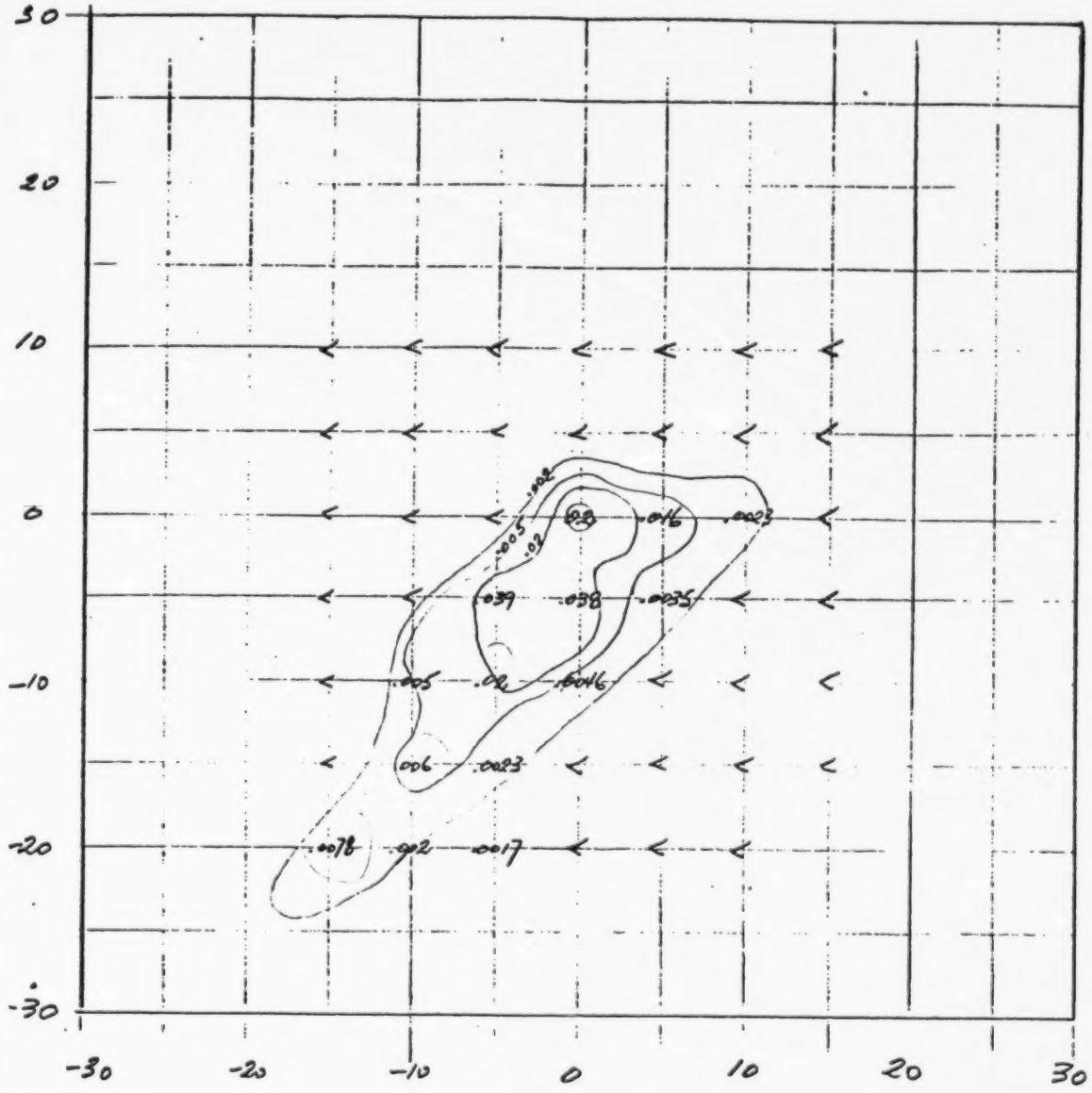
TRACER SAND CONCENTRATION

STATION : 8

DATE : 23rd JUNE 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.



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FRASER FORESHORE SEDIMENT

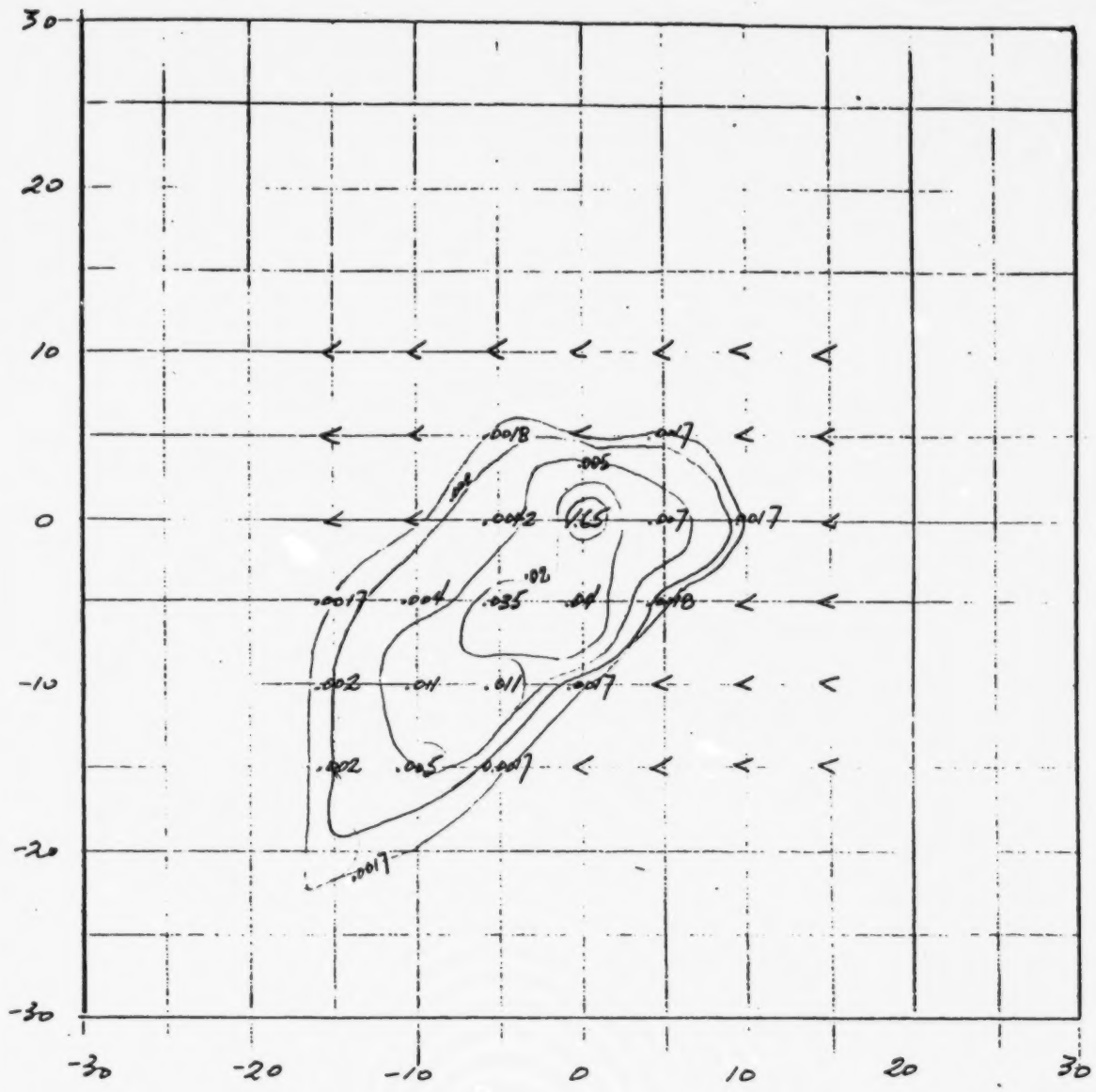
TRACER SAND CONCENTRATION

STATION : 8

DATE : 25th JUNE 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.



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FRASER FORESHORE SEDIMENT

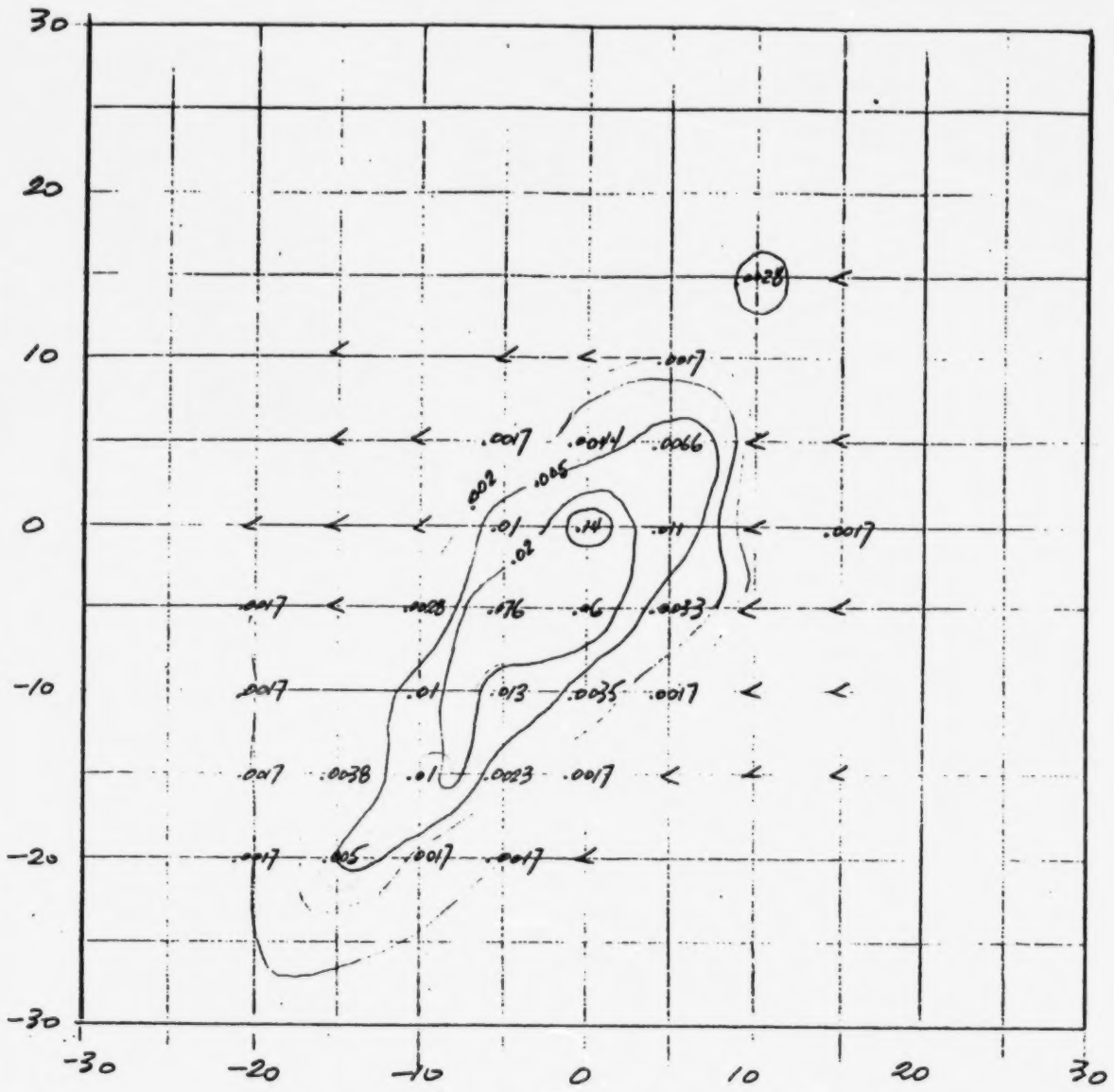
TRACER SAND CONCENTRATION

STATION : 8

DATE : 4th July 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.



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FRASER FORESHORE SEDIMENT

TRACER SAND CONCENTRATION

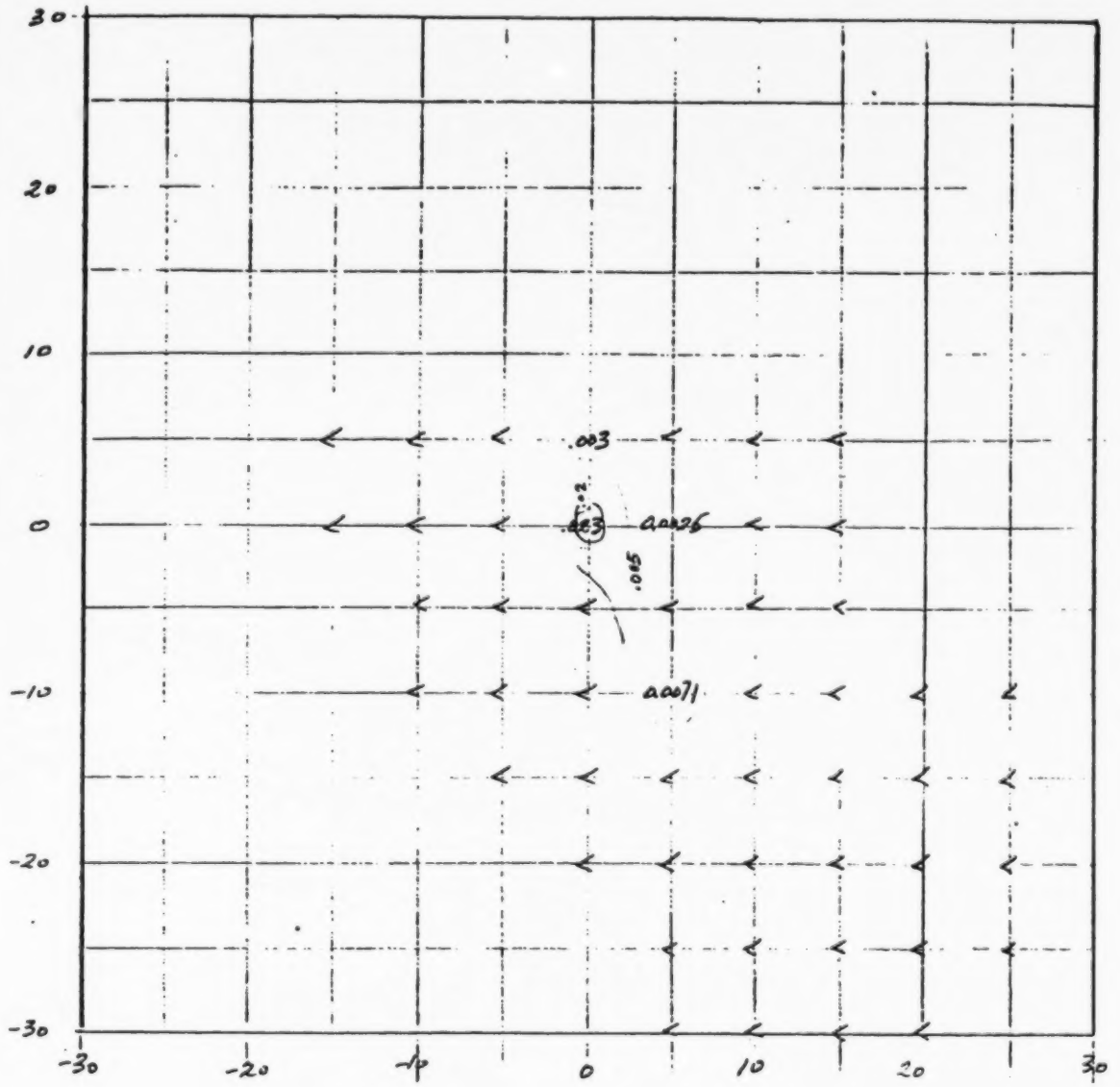
STATION : 8

DATE : 9th July 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

STATION 9



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FRASER FORESHORE SEDIMENT

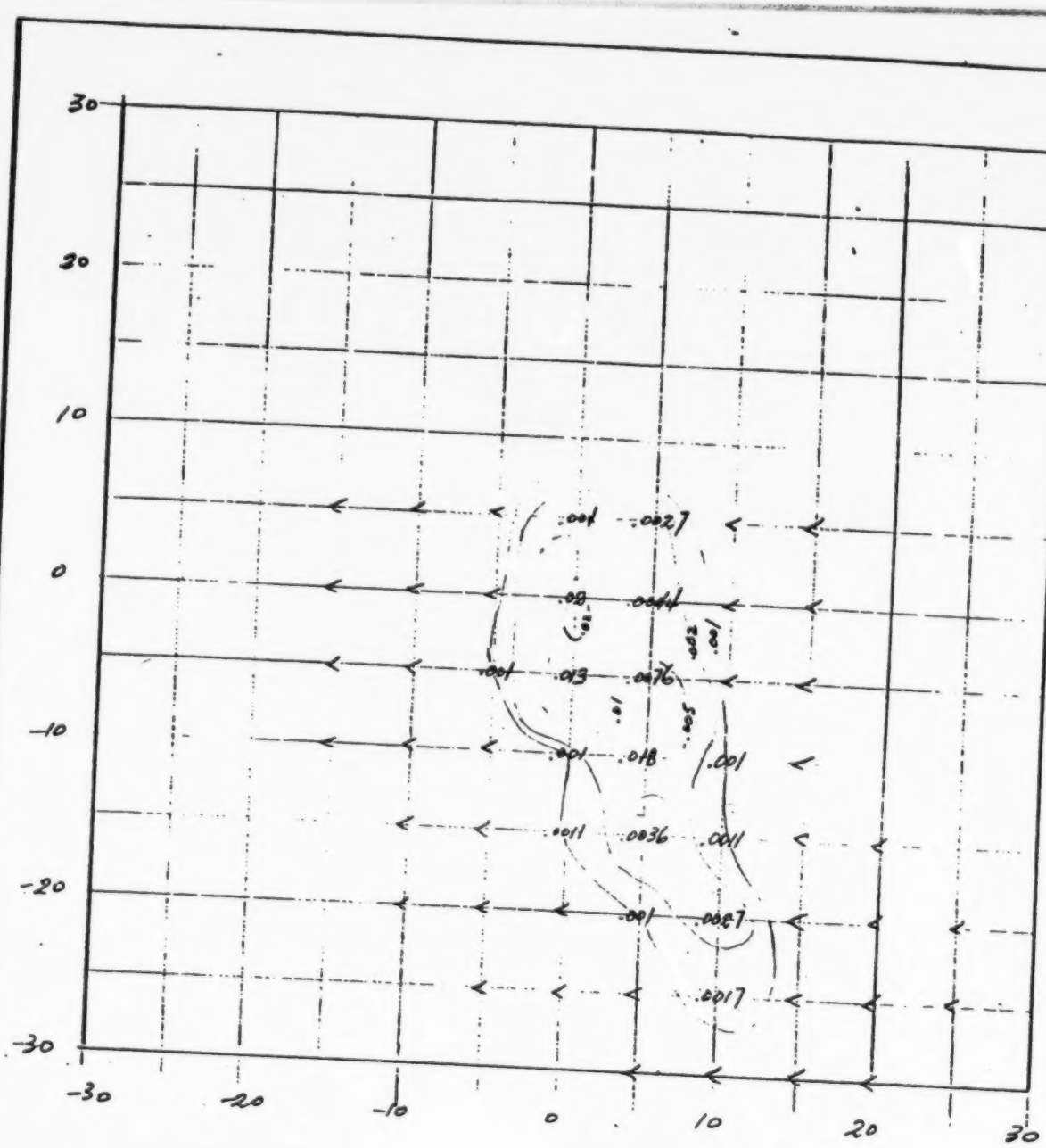
TRACER SAND CONCENTRATION

STATION : 9

DATE : 23 JUNE 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.



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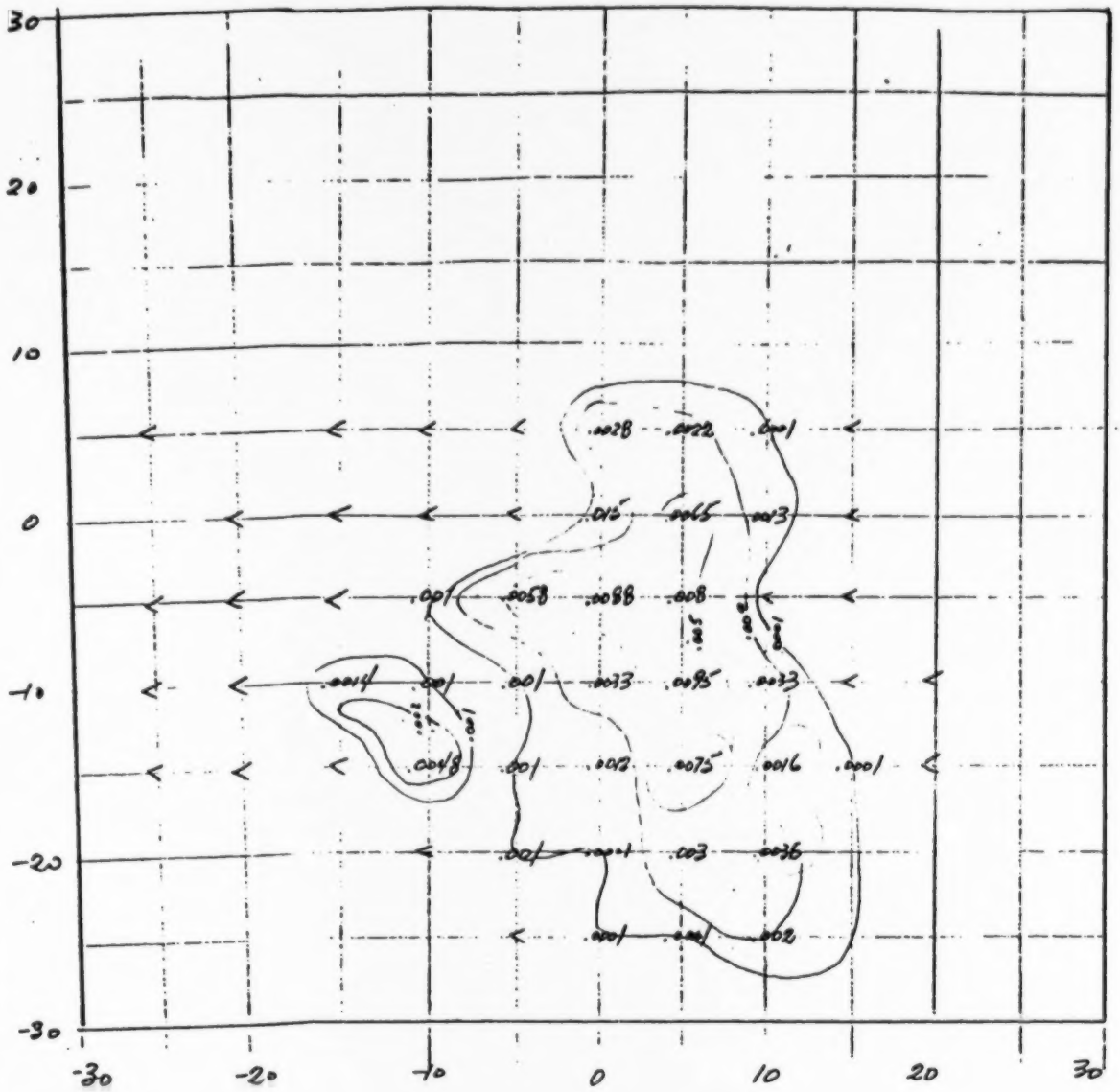
FRASER FORESHORE SEDIMENT
TRACER SAND CONCENTRATION

Scale 1:400

STATION: 9

DATE: 25th JUNE 82

WESTERN CANADA HYDRAULIC LABORATORIES LTD.



$< = < .001\%$

FRASER FORESHORE SEDIMENT

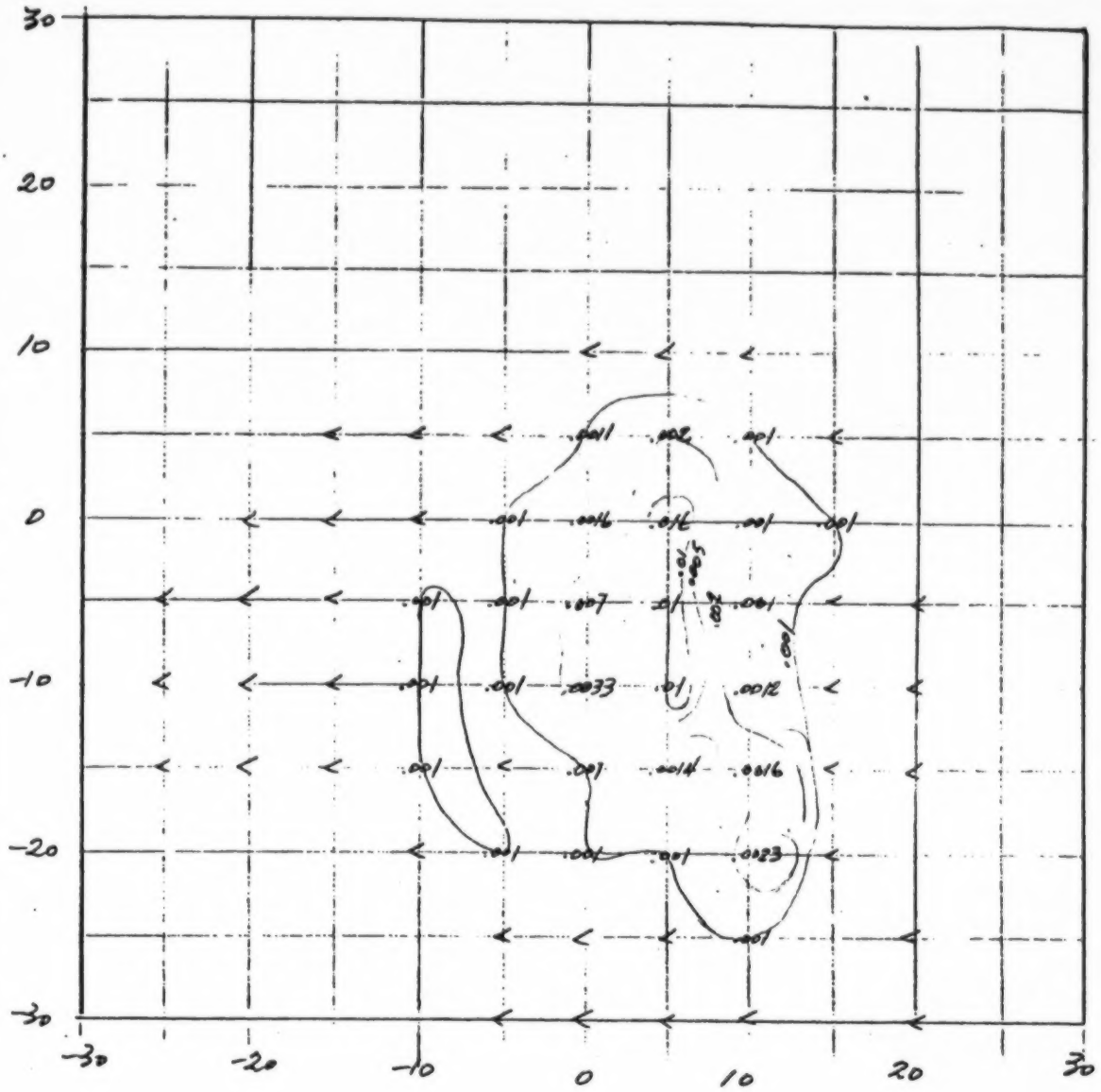
TRACER SAND CONCENTRATION

STATION : 9

DATE : 4TH July 82

Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.



< = < .001%

FRASER FORESHORE SEDIMENT

TRACER SAND CONCENTRATION

STATION : 9

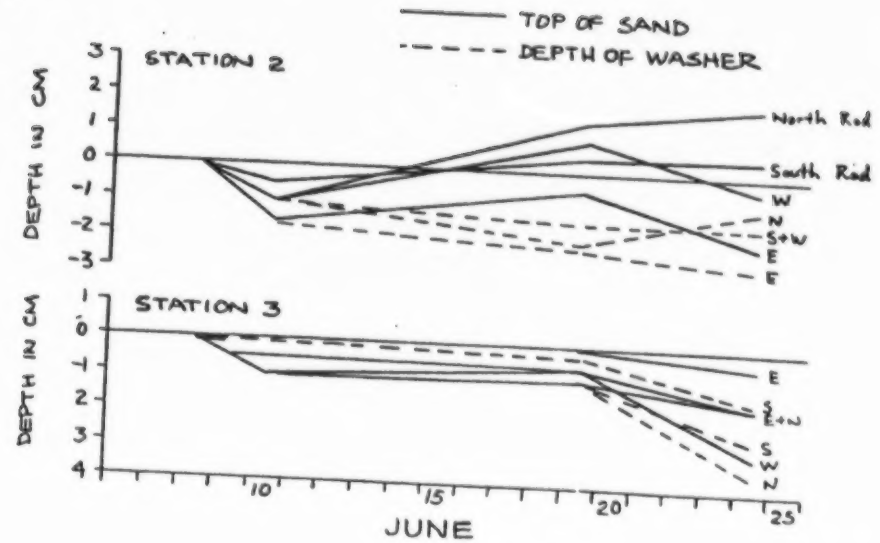
DATE : 9th July 82

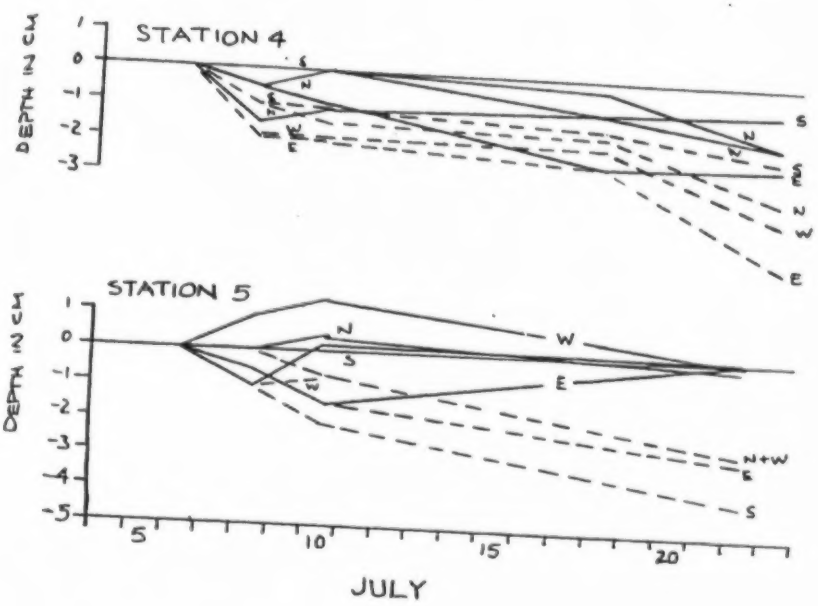
Scale 1:400

WESTERN CANADA HYDRAULIC LABORATORIES LTD.

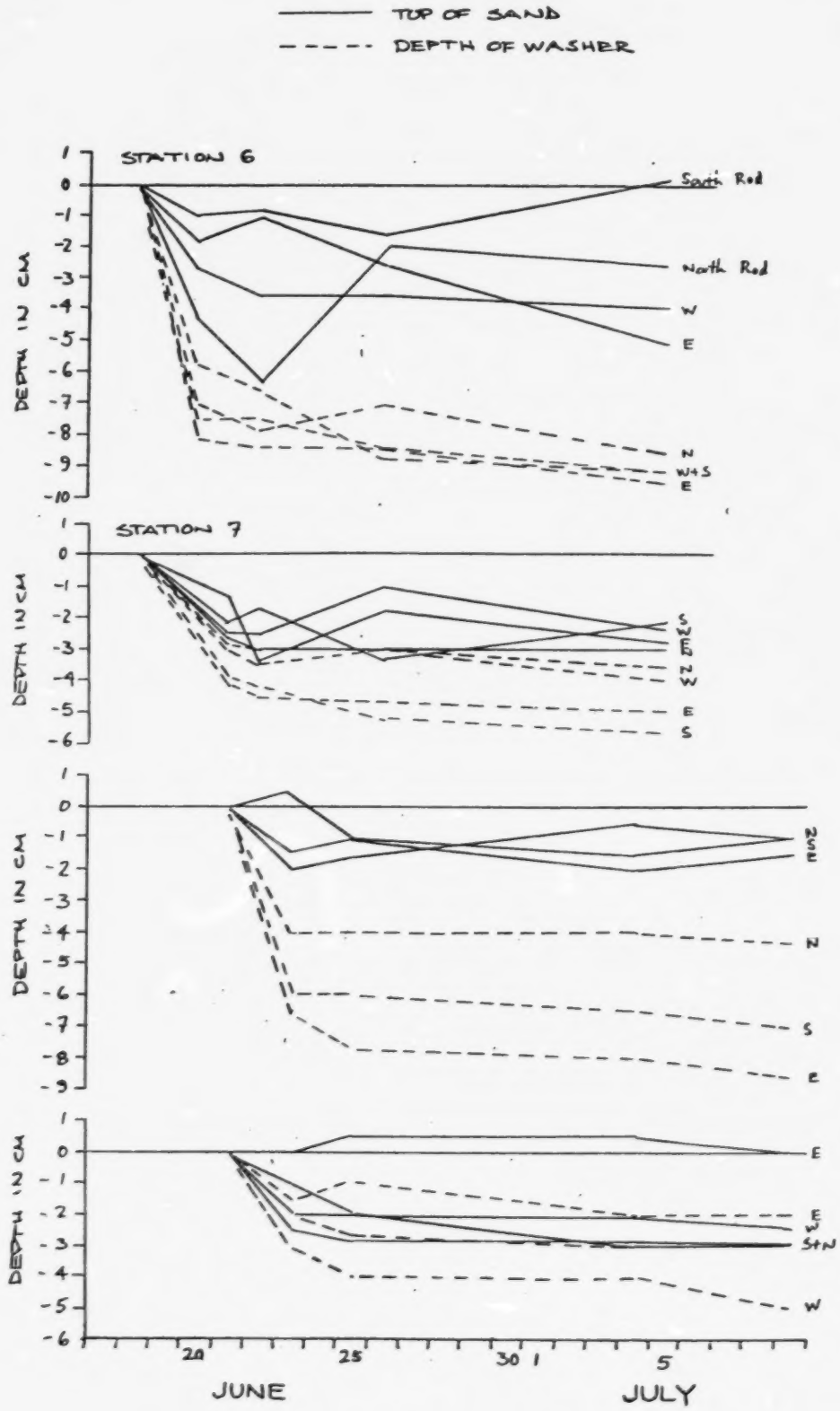
APPENDIX C

DEPTH OF DISTURBANCE MEASUREMENTS





DEPTH OF DISTURBANCE ROD MEASUREMENTS - STURGEON BANK



DEPTH OF DISTURBANCE ROD MEASUREMENTS - ROBERTS BANK

APPENDIX D

LISTING OF NUMERICAL DISPERSION PROGRAM

```
!!!!!!!!!!
!!!!!!!!!!      PROGRAM DISPERS; PROGRAM DEVISED FOR THE SOLUTION
!!!!!!!!!!      OF THE TWO DIMENSIONAL ADVECTION-DIFFUSION  PROCESS
!!!!!!!!!!      OF SEDIMENT TRACER MOTION ON THE FORESHORE OF THE
!!!!!!!!!!      FRASER RIVER.  THE EQUATION TO BE SOLVED IS OF THE
!!!!!!!!!!      FOLLOWING TYPE:
!!!!!!!!!!
!!!!!!!!!!      (DELTA) / (DELTA TIME) * CONCENTRATION =
!!!!!!!!!!      DIFFUSION  COEFFICIENT * LAPLACIAN (CONCENTRATION)
!!!!!!!!!!      - ADVECTION COEFFICIENT * GRADIENT (CONCENTRATION)
!!!!!!!!!!
!!!!!!!!!!      THE GENERAL SOLUTION OF WHICH IS :
!!!!!!!!!!
!!!!!!!!!!      C(t+1,i,J)=C(t,i,J)+D11*DELTAT/DELTAX**2.*(C(t,i+1
!!!!!!!!!!      ,J)+C(t,i-1,J)-2.*C(t,i,J))+D22*DELTAT/DELTAY**2.*
!!!!!!!!!!      (C(t,i,J+1)+C(t,i,J-1)-2.*C(t,i,J))-ADVECTION
!!!!!!!!!!
!!!!!!!!!!      Where 'advection' is defined as a function of the
!!!!!!!!!!      relative position of the cell for which computa-
!!!!!!!!!!      tions are performed . There are nine different
!!!!!!!!!!      discrete 'writings' of advection, for the general
!!!!!!!!!!      case of an interior cell . The conditions prescri-
!!!!!!!!!!      bing these different versions of advection, are
!!!!!!!!!!      the following  :
!!!!!!!!!!
!!!!!!!!!!      1) i < ii , j < jj          6) i = ii , j < jj
!!!!!!!!!!      2) i < ii , j > jj          7) i = ii , j > jj
!!!!!!!!!!      3) i > ii , j > jj          8) i < ii , j = jj
!!!!!!!!!!      4) i > ii , j < jj          9) i > ii , j = jj
!!!!!!!!!!      5) i = ii , j = jj
!!!!!!!!!!
!!!!!!!!!!      FOR:
!!!!!!!!!!          C          : CONCENTRATION ( BY VOLUME ) OF
!!!!!!!!!!                       SEDIMENT TRACER
!!!!!!!!!!          D11        : DIFFUSION COEFFICIENT ALONG THE
!!!!!!!!!!                       - X - AXIS, METRE SQUARED/DAY
!!!!!!!!!!          D22        : DIFFUSION COEFFICIENT ALONG THE
!!!!!!!!!!                       - Y - AXIS, METRE SQUARED/DAY
!!!!!!!!!!          W11        : FLUX OF SEDIMENT TRACER ALONG THE
!!!!!!!!!!                       - X - AXIS, METRE/DAY
!!!!!!!!!!          W22        : FLUX OF SEDIMENT TRACER ALONG THE
!!!!!!!!!!                       - Y - AXIS, METRE/DAY
!!!!!!!!!!          DELTAT     : DIFFERENTIAL STEP ALONG THE TIME
!!!!!!!!!!                       AXIS, DAYS ( OR FRACTIONS OF )
!!!!!!!!!!          DELTAX     : DIFFERENTIAL STEP ALONG THE - X -
!!!!!!!!!!                       AXIS, METRES
!!!!!!!!!!          DELTAY     : DIFFERENTIAL STEP ALONG THE - Y -
!!!!!!!!!!                       AXIS, METRES
!!!!!!!!!!          i,J,t      : COMPUTATIONAL NODES ALONG THE DIS-
!!!!!!!!!!                       TANCE ( - X - AND - Y - ) AXES, AND
!!!!!!!!!!                       THE TIME AXIS
!!!!!!!!!!          ii,JJ      : NODULAR LOCATION OF THE INITIAL
!!!!!!!!!!                       TRACER PAD
!!!!!!!!!!
```

```
!!!
```

THE PURPOSE OF THIS GOTO STATEMENT IS TO DIRECT
THE COMPUTATIONAL PROCEDURE TO THE APPROPRIATE
SECTION, DEPENDING ON THE VALUE OF THE PARAMETER
IDENT, PARAMETER IDENTIFYING THE TYPE OF CELL FOR
WHICH THE FINITE DIFFERENCE COMPUTATION IS PERFORMED.
THE FOLLOWING TABLE EXPLAINS THE RELATIONSHIP
BETWEEN 'IDENT', THE SECTION OF COMPUTATION AND
THE NATURE OF THE CELL.

IDENT	SECTION OF COMPUTATION	NATURE OF CELL
1	210	TOP LEFT CORNER CELL
2	220	TOP BOUNDARY CELL
3	230	TOP RIGHT CORNER CELL
4	240	LEFT BOUNDARY CELL
5	250	INTERIOR CELL
6	260	RIGHT BOUNDARY CELL
7	270	BOTTOM LEFT CORNER CELL
8	280	BOTTOM BOUNDARY CELL
9	290	BOTTOM RIGHT CORNER CELL.

SOLUTION FOR TOP LEFT CORNER CELL

averasing of diffusion coefficients

```
210 DXT=DX(I,J)
    DXB=(DX(I+1,J)+DX(I,J))/2.0
    DYL=DY(I,J)
    DYR=(DY(I,J)+DY(I,J+1))/2.0
    DXAV=(DXT+DXB)/2.0
    DYAV=(DYR+DYL)/2.0
    CONNEW(I,J)=CON(I,J)+COEF1*(CON(I+1,J)*DXB-CON(I,J)*DXAV+CON(I,
   1J+1)*DYR-CON(I,J)*DYAV)-SED1*COEF3*(CON(I,J)-CON(I+1,J))
   2-SED2*COEF3*(CON(I,J)-CON(I,J+1))
    GOTO 295
```

```
!!!
```

```
!!!
```

```
!!!
```

```
!!!
```

THE INPUTS TO THE PROGRAM ARE THE FOLLOWING :

1. THE NUMBER OF ROWS AND COLUMNS OF THE COMPUTATIONAL MATRIX.
2. THE DISTANCE AND TIME STEPS. THE TIME OF PRINTOUT AS WELL AS THE TOTAL SIMULATION TIME.
3. AN 'IDENTIFICATION' OF EACH OF THE COMPUTATIONAL CELLS. THIS IDENTIFICATION PARAMETER DETERMINES THE FINITE DIFFERENCE EQUATION TO BE USED, DEPENDING ON THE NATURE OF THE CELL, WITHIN THE COMPUTATIONAL MATRIX. EACH CELL IS EITHER OF THE 'INTERIOR' OR 'BOUNDARY' TYPE.
4. A VALUE OF INITIAL SEDIMENT TRACER CONCENTRATION FOR EACH OF THE COMPUTATIONAL CELLS.
5. A DIFFUSION COEFFICIENT VALUE (ALONG BOTH THE - X - AND - Y - AXES), FOR EACH OF THE COMPUTATIONAL CELLS.
6. VALUES OF SEDIMENT TRACER FLUX (ALONG BOTH THE - X - AND - Y - AXES), FOR EACH OF THE COMPUTATIONAL CELLS.
7. THE LOCATION OF THE INITIAL TRACER PAD WITHIN THE GRID MATRIX.

THE FORMAT OF THE INPUT VARIABLES FOR THIS VERSION OF THE PROGRAM IS THE FOLLOWING :

CARD	VARIABLE	DEFINITION	FORMAT
1	NROW	NUMBER OF ROWS	I5
1	NCOL	NUMBER OF COLUMNS	I5
1	DELTAX	DISTANCE STEP	F5.0
1	DELTAT	TIME STEP	F10.3
1	TPR	INITIAL PRINT TIME	F10.3
1	DTPR	INCREM. PRINT TIME	F10.3
1	TOTAL	PERIOD OF SIMULATION.	F10.3
2	II	X-LOCATION OF THE CELL HAVING AN INITIAL CONCENTRATION LARGER THAN 0.0.	I5
2	JJ	Y-LOCATION OF THE CELL HAVING AN INITIAL CONCENTRATION LARGER THAN 0.0.	I5
3-17	ID	IDENTIFICATION OF CELL LOCATION	15I5
18	SPIKE	INITIAL CONCENTRATION VALUE AT CELL II,JJ	F5.1
19-33.	SEDX	TRACER SAND FLUX (X-ADVECTION) VALUES,AT EACH CELL	15F5.2
34-48.	SEDY	TRACER SAND FLUX (Y-ADVECTION) VALUES,AT EACH CELL	15F5.2
49-63.	DX	X-DIFFUSION VALUES FOR EACH CELL	15F5.2
64-78.	DY	Y-DIFFUSION VALUES FOR EACH CELL	15F5.2

Please note : This program has not been fully calibrated, verified or run for different sets of conditions. The numerical scheme being used is of an explicit nature, subjecting the model to strict stability criteria.
Nevertheless, the model should be adequately stable if the following rule is adhered to :

D*(DELTAT/(DELTAL**2.0)) < 0.5

for :

D : a given diffusion coefficient along the - x - or - y - axis

DELTAL = DELTAX = DELTAY

For a gridded matrix output of up to 15 by 15 cells (this maximum cell number being a function of the format of the variables) to be printed on a single page, pre-select the following printer characteristics :

Horizontal : 12 characters per inch

Vertical : 12 lines per inch, for a form length of 132 lines

The grid may be considered useful when a preliminary contouring of results is wanted. If the grid is not needed, or if a matrix larger than 15 by 15 is required, delete format statements 160 and 165 and modify format statements 170 and 175, by eliminating the extra print spaces.

This program has been written using ANSI FORTRAN-77, to be implemented on a FORTRAN-66 compiler, rewriting of most of the DO and IF statements would be necessary.

$

POOR

QUALITY

ORIGINAL